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THE INFLUENCE OF VENTILATION ON DISTRIBUTION AND DISPERSAL OF GASEOUS CONTAMINANTS UNDER CONFINED CONDITIONS

by

© PATRICK GABRIEL BRANNIGAN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Influence of Ventilation on Distribution and Dispersal of Gaseous Contaminants Under Confined Conditions" submitted by Patrick Gabriel Brannigan in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The principle objective of this project was to investigate the effect of different ventilation parameters on the mean concentrations and the distribution patterns of atmospheric ammonia and carbon dioxide in an environmental chamber. The dimensions of this chamber represented a full scale section of a pig barn. Facilities were installed in the chamber for the simulation of sensible heat and gas production of twenty pigs. The independent variables used were ventilation rate, outlet height, heat condition, distance from inlet and height from floor. The variable heat condition consisted of comparison of gas concentrations and distribution patterns with and without simulation of heat production. Sampling procedure involved collection of gas concentration and temperature data in a longitudinal plane within the chamber.

Statistical analysis of the data showed that:

1. No practical differences were found between the distribution patterns of carbon dioxide and ammonia.
2. All of the independent variables except heat condition were found to significantly affect the ammonia concentration. With carbon dioxide, it was found that all of the variables were significant.
3. The low outlet height reduced the concentration of both gases under the isothermal heat condition. No practical effect of outlet height was found under non-isothermal heat conditions.
4. Multiple regression analysis yielded a predication equation for both gas concentrations using ventilation rate as the independent variable.

5. Significant correlations for both gases were found between concentration and temperature. Concentration equations are presented for both gases at the three ventilation rates used using temperature as the independent variable.

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1. INTRODUCTION

A continuous supply of uncontaminated air is a requirement for health and optimum performance of farm animals. Air contaminants are produced both by the animal and by factors within its immediate environment. Animals produce moisture and gases in exhaled air, dust in the form of tissue debris, and micro-organisms which possibly may be pathological. Air contaminants also include moisture and gases resulting from the evaporation and breakdown of faeces and urine, dust from feed or bedding, and micro-organisms which may multiply at a fast rate in an environment modified by the presence of animals.

The production of these air contaminants does not present any problems to animals in their natural habitat. Natural air movement serves to dilute air contaminants and to transport them away from the immediate vicinity of the animal. Alternatively, if the animal senses an increase in the pollution of its micro-environment, it has the option to move from the contaminated zone. Under controlled atmosphere conditions, however, the situation is quite different. Many of the advantages of maintaining a thermal environment within the optimum range have, in some cases, been lost due to the presence of high concentrations of air pollutants. Under these enclosed conditions, animals do not usually have the option of moving away from a polluted micro-environment.

Noxious gases present in the atmosphere of farm buildings have given rise to concern as a result of the odours they cause and because of their effect on the health and well-being of stock. The storage of slurry beneath slatted floors has created conditions which are conducive to the production of noxious gases. Deaths have occurred in cases where large quantities of these gases were released over a short period of time.

Problems also have been shown to occur in poultry houses under conditions of restricted ventilation. A number of ventilation systems have incorporated facilities for removal of specific gases that might cause a problem. Generally, these systems were based on the theory that heavy gases tended to accumulate near floor level while light gases tended to move from their point of generation to accumulate at higher levels.

The main purpose of this investigation was to study the distribution of a heavy and a light gas under different conditions of ventilation and heat condition.

2. REVIEW OF LITERATURE

2.1 Composition of Uncontaminated Air

The term uncontaminated air is probably in itself a misnomer as the composition of atmospheric air varies somewhat depending on the locale. However, an international body (16) has established the composition of dry air to be 78.09% nitrogen (N_2), 20.95% oxygen (O_2), 0.93% argon (Ar), and 0.03% carbon dioxide (CO_2). Although the composition of air is arbitrary , this forementioned composition is regarded as exact by definition.

2.2 Noxious Gases in Livestock Buildings

In addition to the components of clean air, the atmosphere of a livestock building contains varying quantities of ammonia (NH_3), methane (CH_4), hydrogen sulphide (H_2S) and carbon monoxide (CO). Also, the CO_2 concentration of the atmosphere in such buildings is higher than that of the outside air (25, 5).

2.3 Noxious Gases Produced By Livestock

Carbon dioxide is the gas produced in greatest quantity by farm animals. The energy utilized by animals results from the metabolism of carbon-containing compounds. Carbon dioxide is one of the by-products of this metabolic process. This gas is carried from the cells via the venous system to the lungs where respiration takes place. Respiration involves the gaseous exchange between an organism and its environment (14). In this case, CO_2 in the blood is exchanged with the O_2 of the inhaled air in the lungs. The respired CO_2 is then voided by the animal with the exhaled air. The CO_2 content of expired air varies with the species, level and type of feeding, and frequency of respiration. In general ,the CO_2 content usually increases to 4 - 5%,while the O_2 content is reduced to approximately 16% (14).

In addition to the CO_2 in the expired air, there is also an appreciable quantity produced by the fermentation taking place in the

alimentary canal. Dukes (14) cites evidence to show that, for example, at least 10% of the CO_2 produced by goats originates in the alimentary canal. With dairy cows on a high plane of nutrition, the CO_2 produced as a result of fermentation can amount to 300 litres per day (8). The effect of environmental temperature and level of feeding on pigs of varying weights on the total CO_2 output has been studied by Fuller and cited by Baxter (5). In general, CO_2 output was found to increase with higher liveweight, increased level of feeding and decreased environmental temperature.

Methane is produced in much smaller quantities than CO_2. It is formed during the fermentation process in the rumen or gut. Significant amounts are produced by herbivores,especially ruminants. Small quantities have been found to be produced by adult pigs and man (8). While a portion of this is absorbed by the lungs and expired, the majority is voided by eructation. Blaxter (8) cites 300 litres of CH_4 per 24 hours as being typical of cows and 50 litres per 24 hours for sheep. Due to the nature of eructation,considerable variation exists in the rate of methane production. In general, the largest rates of excretion occur during feeding and with lower rates corresponding to periods of increased activity (8).

Carbon dioxide and CH_4 are the only gases produced in significant quantities as a result of the animal's metabolic process. The remaining contaminant gases found within a livestock building are produced as a result of the decomposition of waste.

2.4 Noxious Gases Produced by Stored Waste

Noxious gases from animal waste create a serious problem where slurry is stored beneath a slatted floor. This system was thought to be the most economical method of storing slurry. However, subsequent experience has shown that gases produced as a result of the bacteriological decomposition of the slurry have given rise to problems in some instances.

In general, the quantity and type of gas produced varies depending on whether aerobic or anaerobic conditions exist in the slurry.

2.4.1 Anaerobic Decomposition of Slurry

The term "anaerobic digestion"" is applied to a process by which organic material is decomposed biologically in an environment devoid of oxygen (12). This process is utilised for the treatment of the solid portion of domestic sewages. In undisturbed stored slurry, this anaerobic condition will occur below the level to which O_2 can diffuse (12). The anaerobic micro-organisms which cause breakdown give rise to a specific combination of gases. The exact process of anaerobic decomposition in farm animal wastes is not yet certain, but it is unlikely to vary very significantly from that of domestic sewage. Clark and Viessman (12) have described the process. During the liquefaction stage, extracellular enzymes break-down the complex organic solids to simpler soluble compounds which are more easily utilized by bacteria. The by-products of this breakdown are volatile organic acids which lead to a drop in pH. At the end of this stage, decomposition of organic acids and soluble nitrogenous products commences. By-products of this decomposition are ammonia, amines, and some gases such as CO_2, CH_4, hydrogen (H_2) and H_2S. The pH rises to a level more favorable to bacterial growth. In addition, this second stage may produce H_2S and other odoriferous compounds. The third stage of the anaerobic decomposition is the alkaline fermentation phase. This occurs at neutral conditions and produces CO_2 and CH_4. The bacteria involved are strict anerobes and have been difficult to study.

Clark and Viessman (12) also suggest that the main gaseous products of anaerobic digestion are CO_2 and CH_4 in a proportion of 3:7 with traces of H_2S and CH_4. They estimate that the total quantity of

gas from 1 lb. of volatile material is 16-18 litres. In a preliminary study on the anaerobic degradation of 11 litres of pig slurry, Hobson, cited by Baxter (5), found a total gas production of 17 litres between the fifth and the nineteenth days. Analysis of the gas on the twelfth day indicated a composition of 82% CO_2, 17% CH_4, 1% H_2 and traces of other gases. The proportion of CO_2 to CH_4 is different to that suggested by Clark and Viessman (12). This may be due to some characteristics of pig slurry that differ from domestic sewage.

2.4.2 Aerobic Decomposition of Slurry

The process of aerobic decomposition is considered to be the most feasible method of reducing the biochemical oxygen demand of animal waste. This process also depends on bacteriological action to break down the waste. Oxidation is the process by which molecular O_2 combines with organic and inorganic compounds to produce energy. Bacteria involved are either strict aerobes or facultative anaerobes. These latter, which are commonly found in domestic sewage, can obtain their energy under aerobic or anaerobic conditions. Gases produced as a result of aerobic digestion are CO_2 and NH_3. If O_2 is supplied at a continuous rate in sufficient quantities, aerobic conditions will be maintained. However, if the supply is discontinued for a period, anaerobic conditions will set in with the consequent production of the associated combination of gases.

2.5 Physiological Effects of Noxious Gases on Livestock

A detailed account of the physiological effect of the different gases is not considered relevant here. However, a short general note on the more important gases which may be involved is given below.

2.5.1 Carbon Dioxide

This gas is not in itself poisonous. It is lethal only at very high concentrations where it can cause death through asphyxiation.

Concentrations of 10% can cause violent panting and exposure of a few hours to concentrations of 25% will cause death (25). Taiganides and White (31) have calculated that, in a tightly constructed piggery, a breakdown in the ventilation system will cause death within 6-8 hours due to CO_2 asphyxiation.

2.5.2 Methane

This gas is similar to CO_2 in that it acts as an asphyxiant. It is not usually present in as large a quantity as CO_2. Highly flammable, it may cause an explosion when present in a concentration of 5% (31). Levels as high as 8% were reported by McAllister and McQuitty (25) prior to the agitation of slurry in enclosed or covered storage pits.

2.5.3 Ammonia

This gas acts as an irritant. Low concentration can irritate both the eyes and throat. In poultry, a concentration of 100 ppm has been shown to cause symptoms of kerato-conjunctivitis (11). The same study revealed that this level of NH_3 caused a decrease in egg production. Concentrations of 20 ppm were found to cause damage to the respiratory tract (4).

Stombaugh et al (30) studied the effects of 12, 61, 103 and 145 ppm of NH_3 on performance and health of pigs. They found that NH_3 concentration significantly decreased feed consumption and hence liveweight gain. There was no significant effect of the efficiency of feed conversion. Preliminary investigations indicated that long term exposure to an NH_3 concentration of 280 ppm was not feasible.

2.5.4 Hydrogen Sulphide

This gas is toxic as well as being an irritant of respiratory tissue. Whereas exposure to CO_2 and CH_4 for a short period of time does not cause any after-effects, exposure to concentrations of H_2S may cause

permanent impairment of health (31). Exposure to 1000 ppm will cause death in humans while exposure to lower concentrations may cause varying degrees of sickness (25).

When defining the maximum safe level of noxious gases, consideration must be given to the time and level of exposure(10) and to the combination of gases likely to be encountered. It has been shown that simultaneous exposure to a combination of NH_3 and H_2S is more toxic than with H_2S alone (21).

2.6 Practical Problems Attributed to Noxious Gas Contamination of Farm Buildings

The factors causing production of noxious gases in farm buildings have been discussed. All other things being equal, the amount of gases produced by the animals in a building will be the same irrespective of the waste handling system used. High noxious gas concentrations are more likely to occur where the waste products are stored within the building. The deep litter system of housing poultry was found to cause increased concentrations of CO_2 and NH_3 (20). Quantities produced from litter have been sufficient to cause kerato-conjunctivitis. Levels greater than 20 ppm have been stated to occur under British conditions while concentrations of 50-100 ppm have been known to occur under winter ventilation conditions in the U.S.A. (24).

The advantages of keeping laying birds at 75-80°F has been described by Payne (28). The economics of this system depend on the cost of supplementary heating. This in turn depends on the minimum ventilation rate that can be continuously maintained under winter conditions. Under this system, it has been shown that CO_2 concentration rather than water vapour is the criterion used to define the minimum ventilation rate.

The problems associated with noxious gases have been much more spectacular in situations where slurry was stored anaerobically beneath

slatted floors. Deaths of humans and stock due to noxious gas contamination have been reported from Europe and North America (1,22,9). These fatalities occurred during agitation of slurry beneath slatted floors or in pits adjacent to the building. Some studies which simulated these conditions revealed that lethal concentrations of NH_3 and H_2S can occur (13,18,25). Hogsved (21) reported that dairy cows suffered chronic gas poisoning during liquid manure removal. Symptoms included subcutaneous bleeding and rotting of the foot. Improvement of the ventilation system resulted in rapid recovery.

2.7 Distribution of Noxious Gases in Farm Buildings

Precautions against the accumulation of noxious gases in farm buildings have been recommended for some time. In general, the precautions were based on the premise that gases which were heavier than air would tend to accumulate near floor level while gases which are lighter than air would tend to accumulate near the ceiling. The King system of natural ventilation, as described by Wooley (35), incorporated floor level outlets for the removal of CO_2. More recently, the Cornell ventilation system for laying birds (33) provides facilities for low level extraction to remove the excess CO_2 (heavier than air) during winter and high level extraction for the removal of NH_3 (lighter than air) during the summer. Taiganides and White (31) in reviewing the properties of the various gases found in farm buildings state that CO_2 and H_2S, being heavier than air, would tend to accumulate near floor level, while NH_3 and CH_4, being lighter than air, would tend to move upwards from their point of generation. Berglund et al (7) stressed the danger that existed to pigs lying on slatted floors near slurry level. Noren et al (27) on the other hand carried out a study on gas distribution in a number of dairy and hog facilities. They discounted the theory that gases tend to accumulate at levels depending on their relative densities.

2.8 Diffusion of Gases

The theory of stratification of gases depending on their relative densities is not valid when one considers that in a binary gas mixture the presence of a concentration gradient gives rise to molecular diffusion (3). Random molecular motion acts in such a fashion as to reduce the concentration gradient and give a homogenous mixture of the two gases. The basic equation for molecular diffusion is stated in Fick's Law. Expressing the concentration of gas A in terms of the partial mass density ρ_A, Fick's Law becomes

$$M_A/A = -D_V(d\rho_A/dy)$$

where:

M_A/A = lb per (hour)(ft^2)

$d\rho_A/dy$ = lb per ft^3/(ft)

D_V = ft^2 per hour (mass diffusivity)

When the gradient is maintained by constantly supplying the diffusing component to the high concentration end of the gradient and removing it at the low concentration end, the flow of the diffusing component is continuous (26). This is somewhat similar to the situation in a farm building where the high concentration end is the point of generation of a noxious gas and the low concentration end is the point where the air is removed from the building. However, gas diffusion in a farm building may not be determined simply by applying Fick's Law. Air movement and temperature gradient probably play an important role in determining the movement of gases from their point of generation. The interrelation of these two factors is very complex and will vary from one situation to another depending on the air movement and temperature pattern.

3. OBJECTIVES

The review of literature has shown that noxious gas contamination of the atmosphere of a livestock building can have effects varying from death at high concentrations to ill-health and reduced performance at lower concentrations. The methods postulated for the removal of heavy and light gases have been described. There is some doubt, however, as to the effectiveness of these methods particularly when one considers that, according to Fick's Law, stratification of gases should not occur.

Accordingly, this project was carried out to determine the following:

(1) The CO_2 and NH_3 concentration variations in a chamber under different ventilation conditions,

(2) The effect of outlet height on the distribution and mean concentration of CO_2 and NH_3 in the chamber,

(3) The effect of heat condition (isothermal or non-isothermal) on the mean concentration and distribution of CO_2 and NH_3, and

(4) The relationship between temperature and gas concentration under non-isothermal conditions.

4. EXPERIMENTAL PROCEDURE

4.1 Materials

4.1.1 Environmental Chamber

This study was carried out in an environmental chamber. The inside of the chamber is shown in figure 3 and the dimensions and general outline in figures 1 and 2. The dimensions were such as to simulate one pen of a typical piggery. The chamber was constructed using spruce 2" x 4" framing clad on the inside with plywood. Quarter inch fir sheathing was used on the walls and roof, while 1/2" poplar sheathing was used on the floor. No walls were installed to partition the dunging passage area from the lying area or the lying area from the feeding passage area. Estimated capacity of a pen of this size is 20 pigs, each weighing approximately 120 lb. Air entered the plenum from the room through slots at both sides near the floor level. An air-conditioner was installed to provide cool air when required. From the plenum, air entered the chamber through a 7'9" x 2" slot inlet.

Ventilation of the chamber was carried out using a 12" centrifugal fan (figure 4). This fan, which extracted air from the chamber, was connected to a calibration duct similar to that described by Jorgensen (23). Adjustment of the ventilation rate was achieved by moving the cone at the end of the duct. Within the chamber, there was a choice of two outlet heights located 19 inches and 75.5 inches from floor level measured to the centre of the outlet (figure 3).

4.1.2 Gas Diffusion Units

The gas diffusion units were designed for the purpose of simulating noxious gas and sensible heat output of 20 pigs. Details of these units are shown in figures 5 and 6. Gas flow from a cylinder was

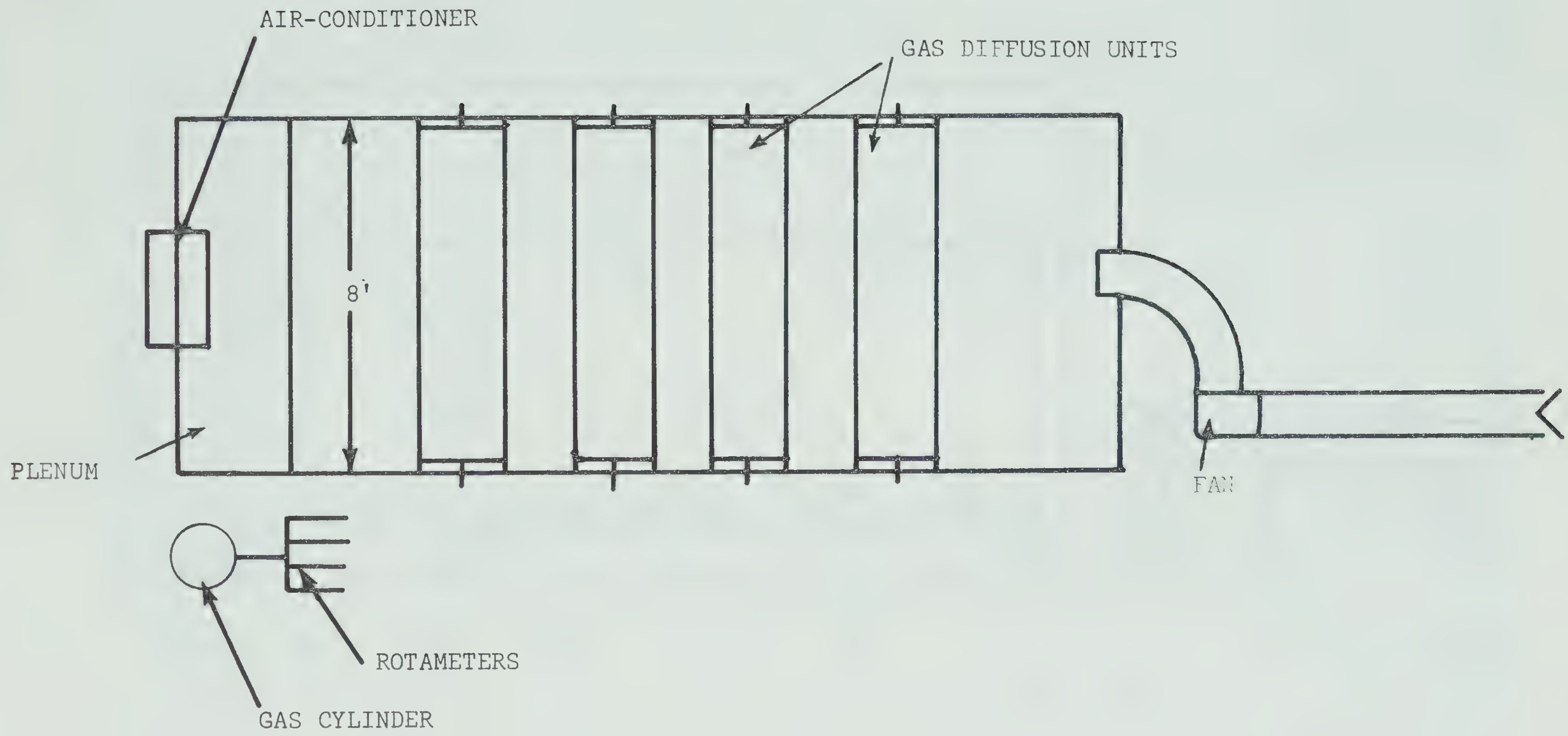

Figure 1. Plan of the environmental chamber.

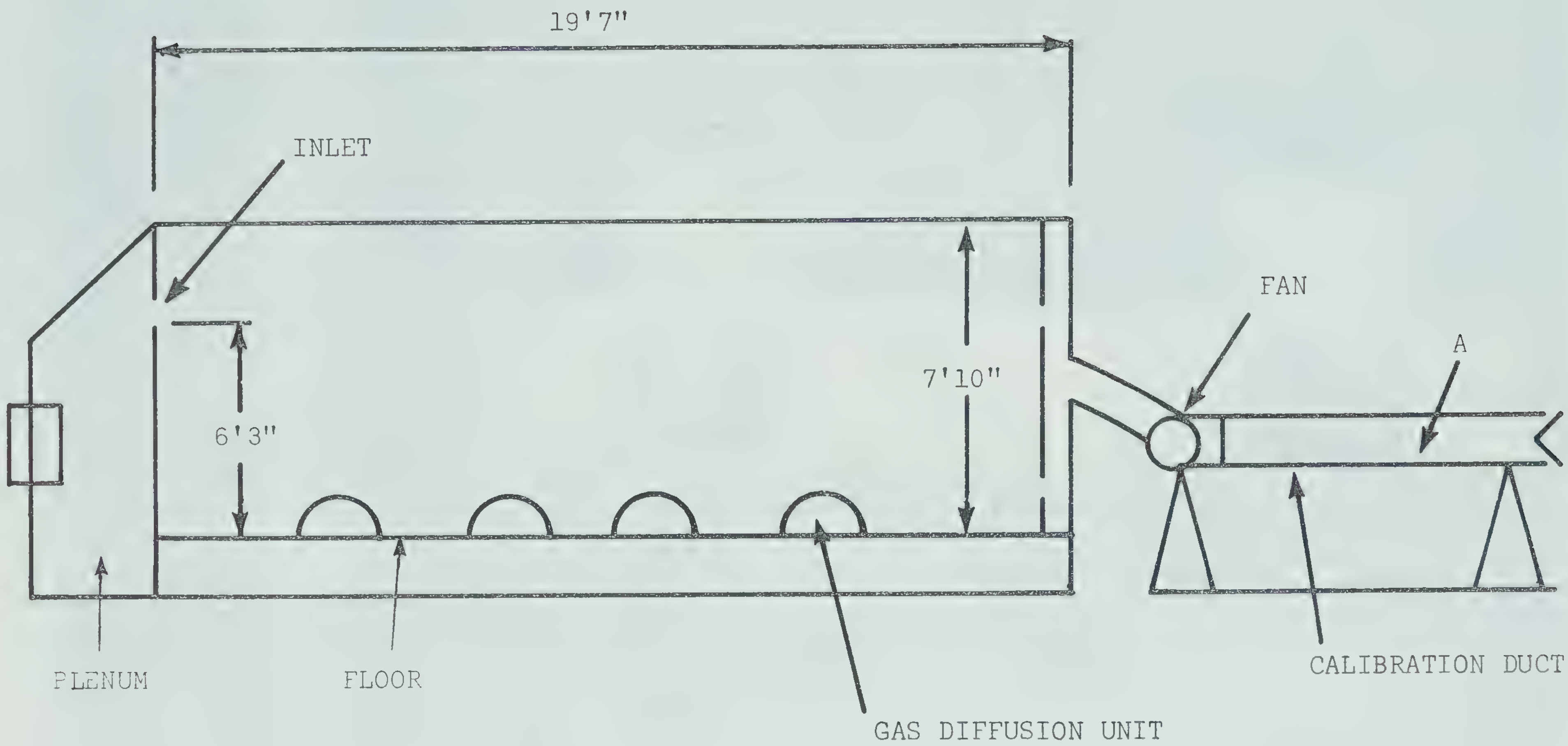

Figure 2. Longitudinal section of the environmental chamber.

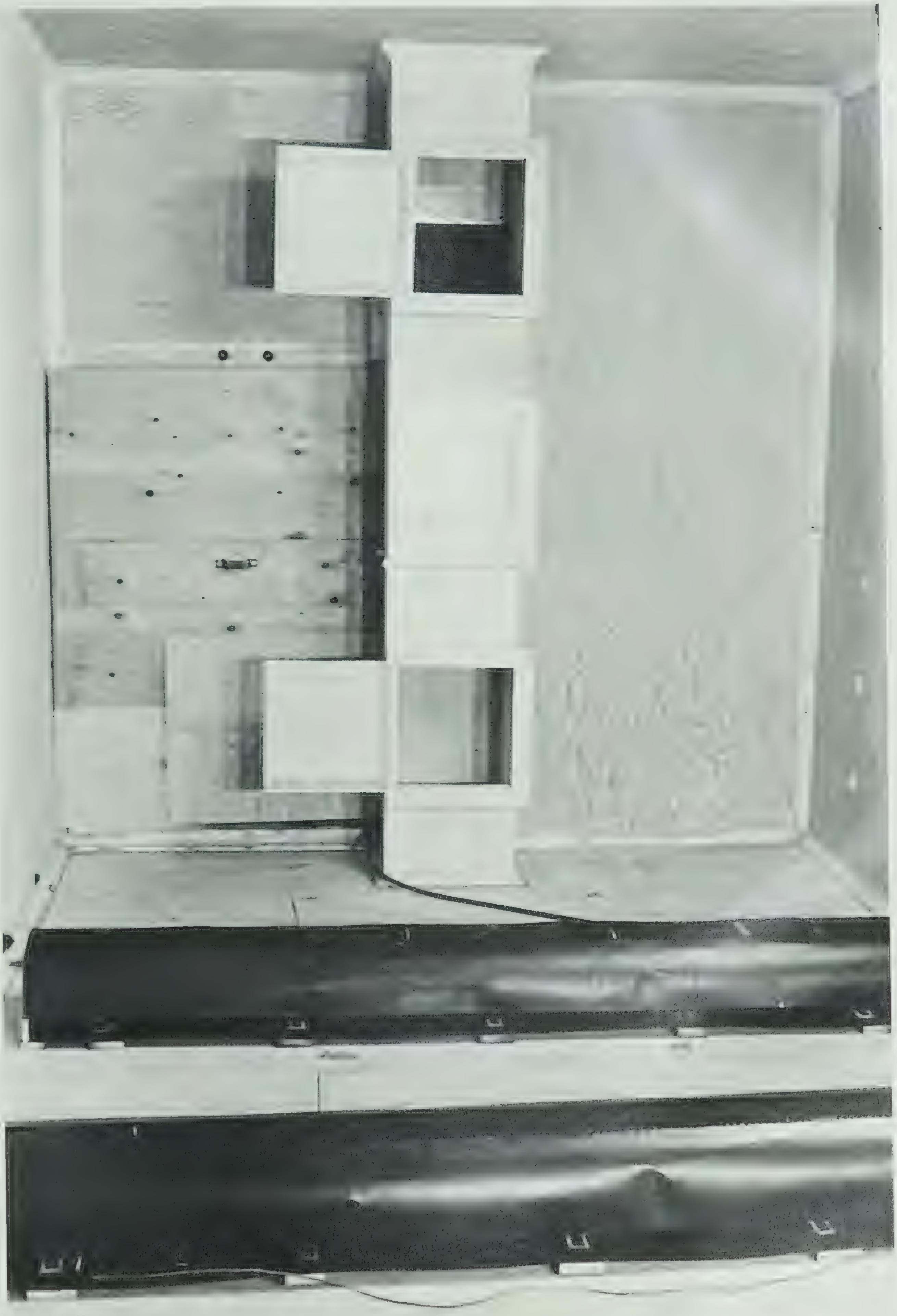

Figure 3: Interior view of the environmental chamber showing the 19.0" and 75.5" outlet points.

Figure 4: Fan and calibration duct.

measured through four rotameters, one for each diffusion unit. From each rotameter, gas flowed to a T section where the flow divided to enter the gas diffusion unit at both ends. Diffusion of the gas took place through a 0.014 inch hole situated centrally in each section of the acrylic piping. The decreasing bore of the pipe from outside to centre helped to maintain pressure in the full length of the pipe, thus giving a fairly even flow from each hole.

In addition to facilities for diffusing gas into the atmosphere, each of these four units had 11 feet of 26 gauge nickel chromium heating elements. The calculated heat output of each was 1285 BTU per hour, which is approximately equivalent to the sensible heat output of five 120 lb. pigs (2). The base and cover of the units was 28 gauge galvanized sheathing coated with flat black paint. The use of four of these units thus made it possible to simulate gas production and sensible heat output of twenty 120 lb. pigs.

4.1.3 Air-Conditioner

Use of the heating elements would have resulted in very high temperatures in the chamber as the air temperature in the laboratory was 70°F. To prevent a large rise in temperature while the heating elements were operating, a 7,500 BTU per hour air conditioner was used to cool the air in the plenum prior to entering the chamber. The effect of using the heating elements in conjunction with the air conditioner was monitored by comparing it with a duplicate set of runs which had no modification of temperature. The condition using the heating elements and air-conditioner was designated 'non-isothermal' heat condition while the other heat condition was designated 'isothermal'. As the cooler operated at a constant rate, the temperature of the air entering the chamber varied depending on the

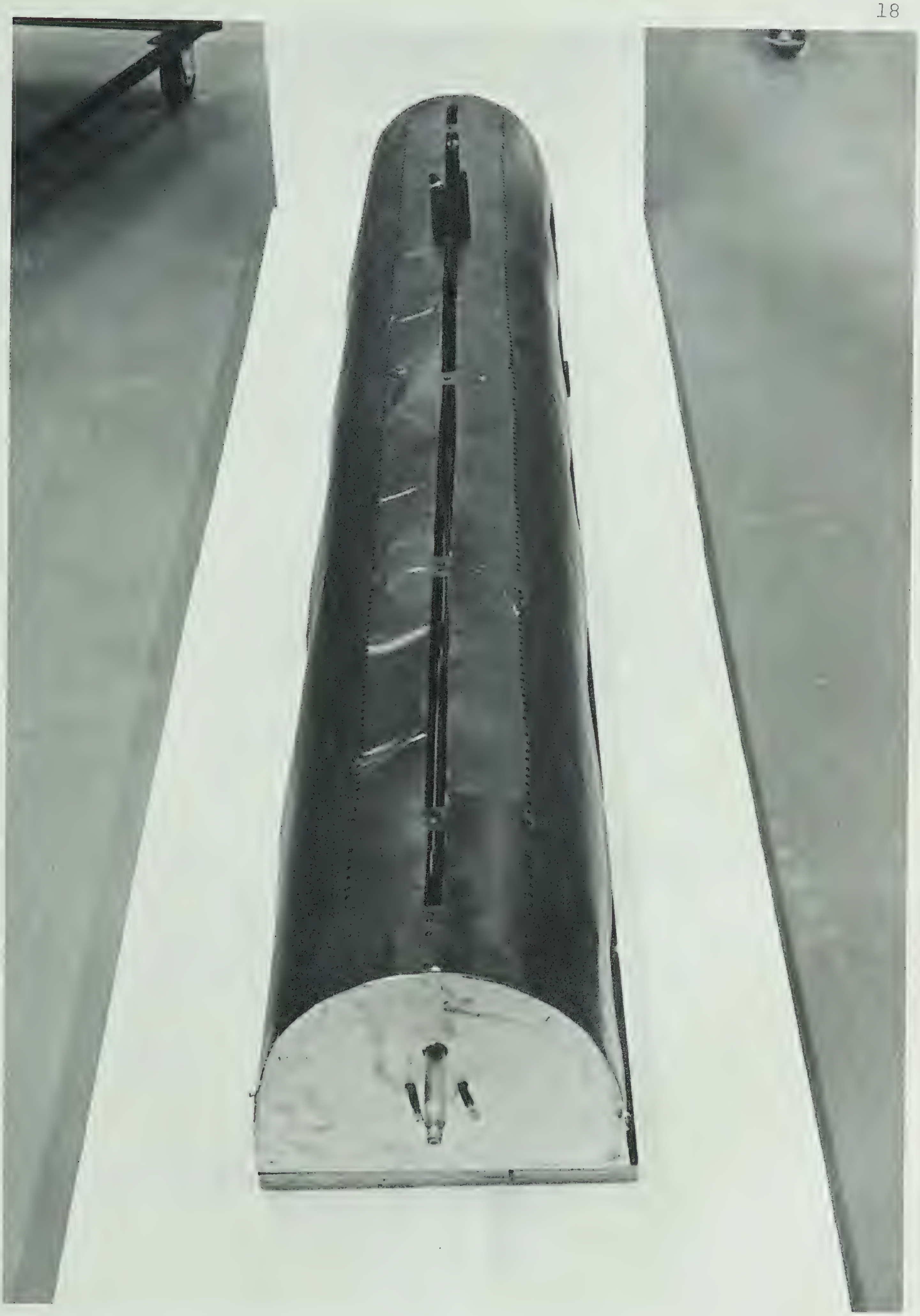

Figure 5: Gas diffusion unit.

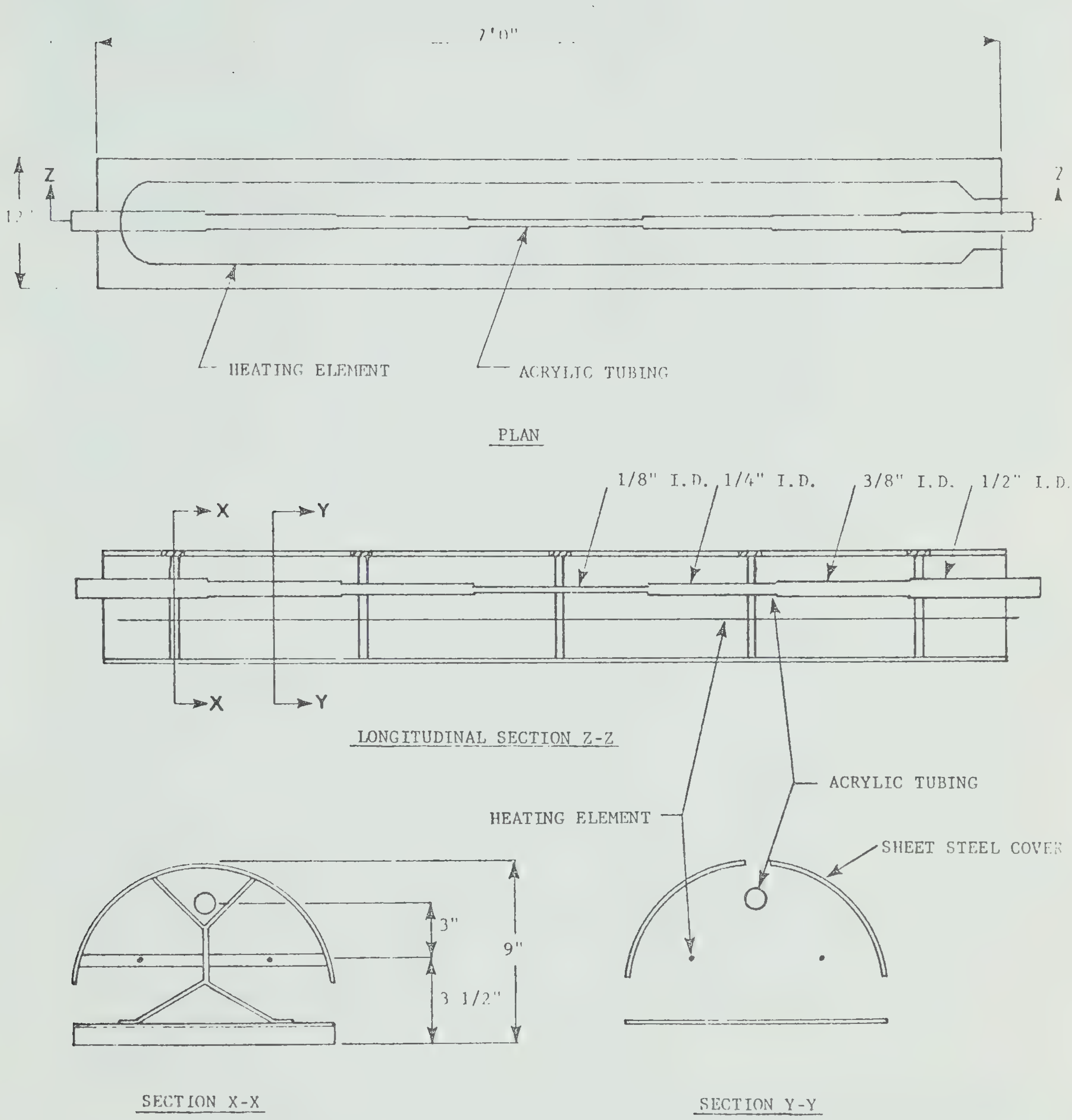

Figure 6. Details of a gas diffusion unit.

ventilation rate. The temperature of the air entering the chamber was measured with a thermocouple placed centrally in the inlet slot. Mean temperatures of the air entering the chamber during the non-isothermal runs were $58.5^{\circ}F$, $60.5^{\circ}F$, and $63.5^{\circ}F$ for ventilation rates of 165cfm, 261 cfm, and 549 cfm respectively

4.1.4 Noxious Gases

Two gases were chosen for this investigation to represent those heavier and lighter than air. Cylinders of high purity CO_2 and NH_3 were purchased from commercial suppliers. Carbon dioxide, having a specific gravity relative to air of 1.53, was representative of the heavy gases, while NH_3 (s.g. 0.59) was representative of the light gases.

Carbon dixoide was used at a rate of 24 litres per pig per hour (i.e. a total of 480 litres per hour), this being approximately equivalent to the CO_2 production of a 120 lb. pig (34). No comparable figures were available for NH_3 as it is produced primarily from decomposing waste. To ensure concentrations within the range of the ammonia analyser and to provide concentrations comparable to that which might be found in practice, the total rate of NH_3 diffusion was fixed at 27 litres per hour.

4.2 Instrumentation

4.2.1 Rotameters

The flow of gas to the gas diffusion units was measured using four Brooks Rotameters (figure 7). The 2-65B model tubes were used for CO_2, while for NH_3 which was used in much lower quantities, 1-65A tubes were installed. A needle valve was incorporated with each of these rotameters for fine adjustment of flow rate. The rotameters had a guaranteed accuracy of 5% and a repeatability of 1% of full scale.

4.2.2 Temperature Instrumentation

Copper-constantan thermocouples were used for temperature

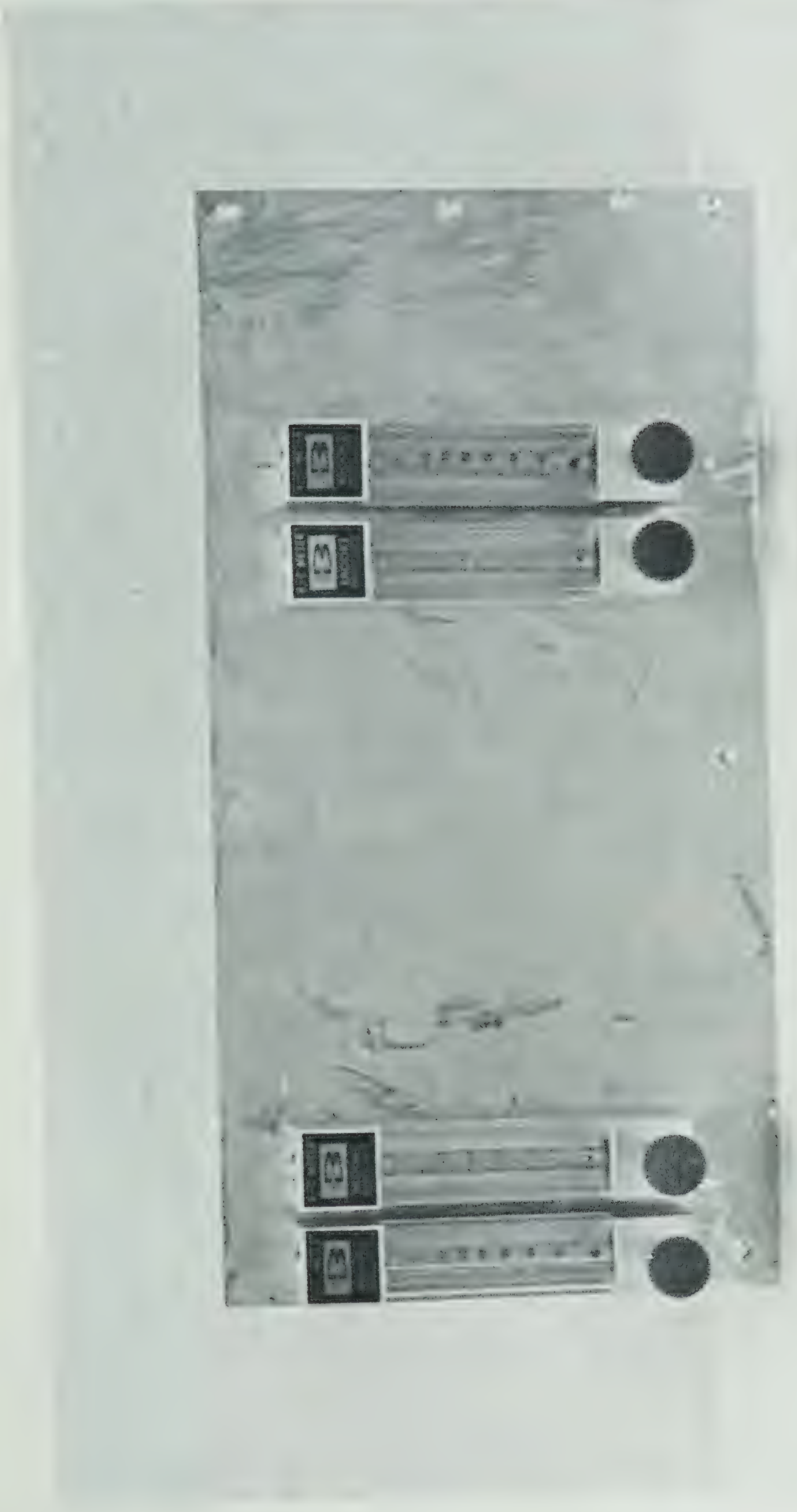

Figure 7: Rotameters used to measure gas flow.

measurements. In all only three thermocouples were used for dry-bulb temperatures. One, already mentioned, was used to sense the temperature of the air entering the chamber from the plenum. The second thermocouple was placed in the outlet duct to sense the temperature of the air leaving the chamber. The third thermocouple was attached to a 4 foot length of 1/4" copper piping. This was used to measure the temperature of the air immediately after taking a gas sample at the same sampling point. These three thermocouples were wired into one station on a Honeywell 24-point temperature recorder. Thus, any of the three temperatures could be measured as required during an experimental ran.

4.2.3 Gas Analysers

Measurements of gas concentration were made using two Beckman Model 315A non-dispersive infra-red analysers (figure 8). As these analysers are specific for a particular gas, separate units were used for CO_2 and NH_3. These gas analysers operate on the principle of measuring the differential absorption of infrared energy. Figure 9 shows a simplified schematic diagram.

Two infrared sources are used, one for the sample cell and one for the reference cell. Both beams are simultaneously blocked ten times per second by the chopper. In the unblocked condition, each beam passes through the associated cell into the detector.

The sample cell is a flow-through tube that receives a continuous stream of sample. The reference cell is a sealed tube filled with a reference gas. This reference gas is chosen for negligible absorption of infrared energy of those wavelengths absorbed by the sample component of interest.

Each of the beams are transmitted through the cell to the detector.

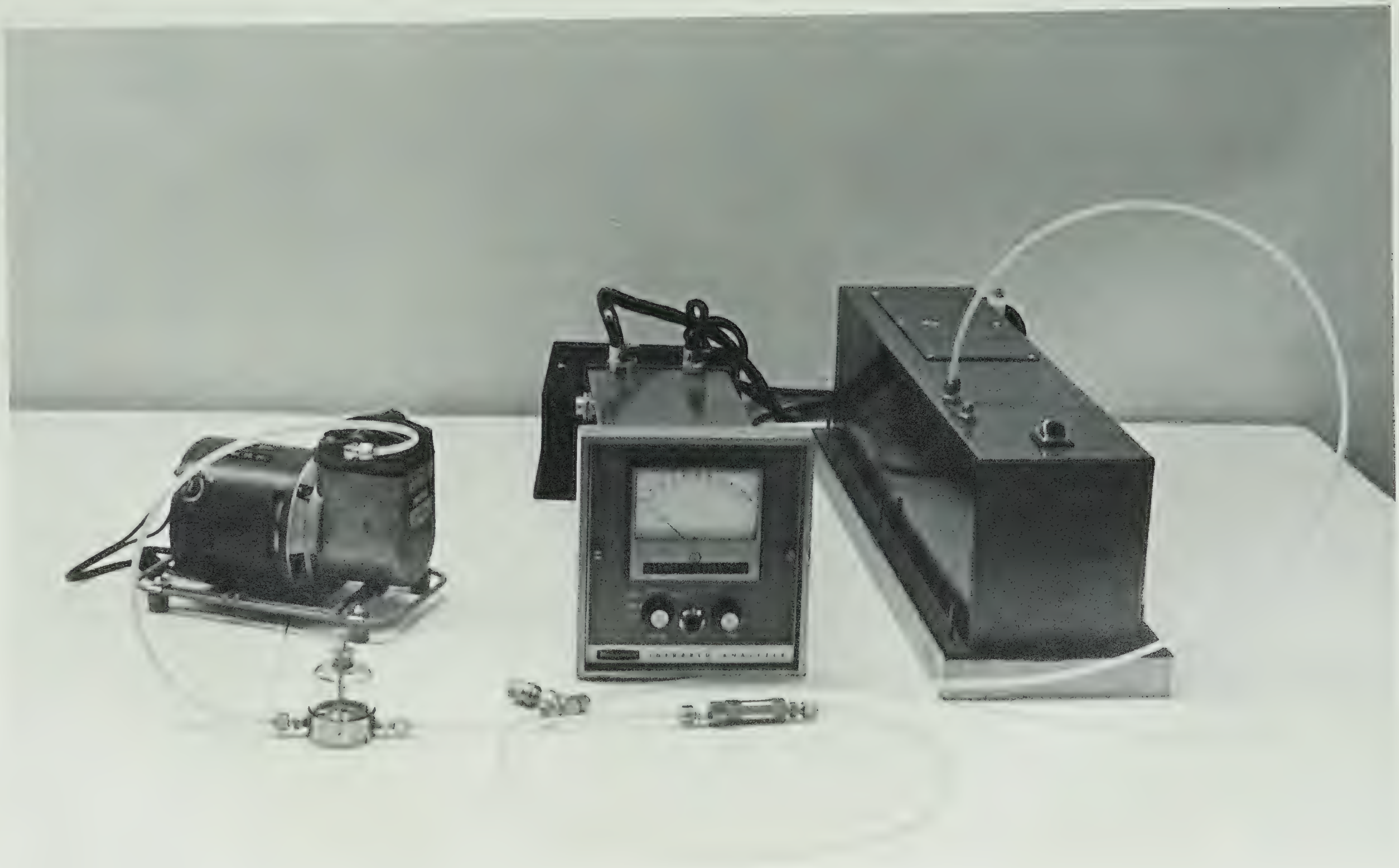

Figure 8: Gas analyzer and sampling pump.

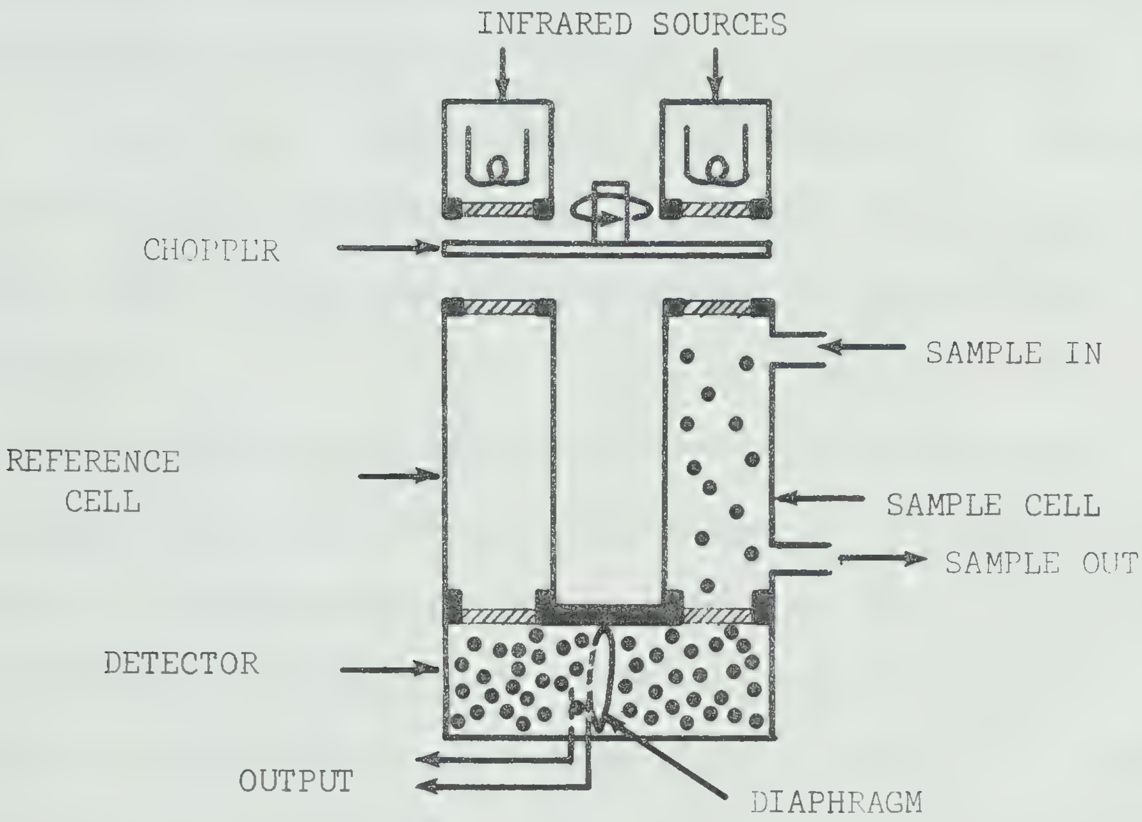

Figure 9. Schematic diagram of non-dispersive infrared gas analyser.

The detector consists of two sealed compartments of equal volume separated by a flexible metal diaphragm. Each compartment has an infrared transmitting window to permit entry of the corresponding infrared beam. Both of these compartments are filled at the same sub-atmospheric pressure with vapour of the component of interest.

When the infrared beam is in the unblocked condition, the presence of the component of interest in the sample stream causes a difference in energy levels between the sample and reference side of the detector. Because of this, the gas in the reference side of the detector is heated more than that in the sample side. Higher temperature in the reference side causes higher pressure which in turn causes the diaphragm to distend towards the sample compartment.

When the beam is blocked, the temperature and pressure in the two compartments equalises causing the diaphragm to return to its original position. Therefore, as the chopper blocks and unblocks the beam, the diaphragm pulses. This pulsing of the diaphragm is converted to an electronic signal which gives a readout on the meter (6). Gas concentration of the sample is determined by reading from a calibration curve.

4.2.4 Micromanometer

Measurement of the velocity pressures in the calibration duct was carried out using a Flow Corporation model MM3 micromanometer connected to a pitot-static tube. The manometer fluid used was butyl alcohol (specific gravity = 0.8166 at 75°F). Accuracy quoted for this instrument is 0.0002" of manometer fluid.

4.3 Methods

4.3.1 Calibration of Ventilation Rate

Measurement of velocity pressures within the calibration duct was carried out at point A (figure 2). The method used has been described

by Jorgensen(23). A horizontal and vertical traverse of velocity pressures was measured using the pitot-static tube and micromanometer. Adjustment of ventilation rates was achieved by moving the cone at the end of the duct. Details of the method used and the calculations are shown in Appendix I. Three settings of the cone were used and the ventilation rates measured for these settings were 165, 261 and 549 cfm respectively. These correspond to air-change rates per hour of 7.8, 12.3, and 25.8 respectively.

4.3.2 Start Up-Procedures

Under normal conditions in livestock buildings, a dynamic equilibrium exists between the rate of gas production and the rate of gas extraction in the ventilating air. Increasing the rate of gas production at a constant ventilation rate will result in a higher concentration of gas in the air leaving the building. To achieve equilibrium conditions in the chamber, gas diffusion and operation of the heating elements were commenced some time before sampling. Under conditions where ventilation rate and gas diffusion are constant, the aimed-at equilibrium is theoretically never achieved (29). However, within the limits of the gas analysers used, it was possible to define equilibrium as that condition which existed when gas concentration of the outgoing air was constant. In practice, sampling was commenced ten minutes after a constant gas concentration was recorded in the extracted air.

4.3.3 Sampling Procedure

Sampling was carried out using a 4 foot length of 1/4 inch O.D. copper piping which was connected by plastic tubing to a pump. The pump drew air from the end of the copper pipe and delivered it via a filter to the analyser (figure 8).

Preliminary studies indicated that there was very little difference

in concentrations across the chamber. This was to be expected as the main components of air velocity would be in either a longitudinal or a vertical direction. To detect concentration variations in both a horizontal and a vertical direction, sampling was carried out in one plane three feet from one side wall. In all, 55 sampling points were chosen in such a way that the areas over and in-between the units were sampled. The layout of the sampling points is shown in figure 10. During an experimental run, these 55 points were sampled in random order. A sample was taken by inserting the copper pipe three feet horizontally into the chamber through a sampling hole (figure 11). Immediately after the concentration of the gas sample was recorded, the probe was removed and replaced with a similar probe containing a thermocouple. The dry-bulb temperature was then recorded and sampling of the next point commenced. Before and after sampling, the sampling holes were closed with rubber stoppers.

During experimental runs with CO_2, the air entering the plenum was sampled. The CO_2 concentration of the air entering the chamber was subtracted from the concentration measured at each sampling point prior to statistical analysis.

4.3.4 Experimental Design

Two separate experiments were carried out differing only in the type and quantity of gas used. It has already been stated that, for each trial run, gas concentrations were measured at all 55 sampling points. The independent variables, whose effects were being monitored, were ventilation rate, outlet height, heat condition, distance from inlet and height from floor. The experiments with both gases were of a factorial design consisting of three ventilation rates, two outlet heights and two heat conditions. There

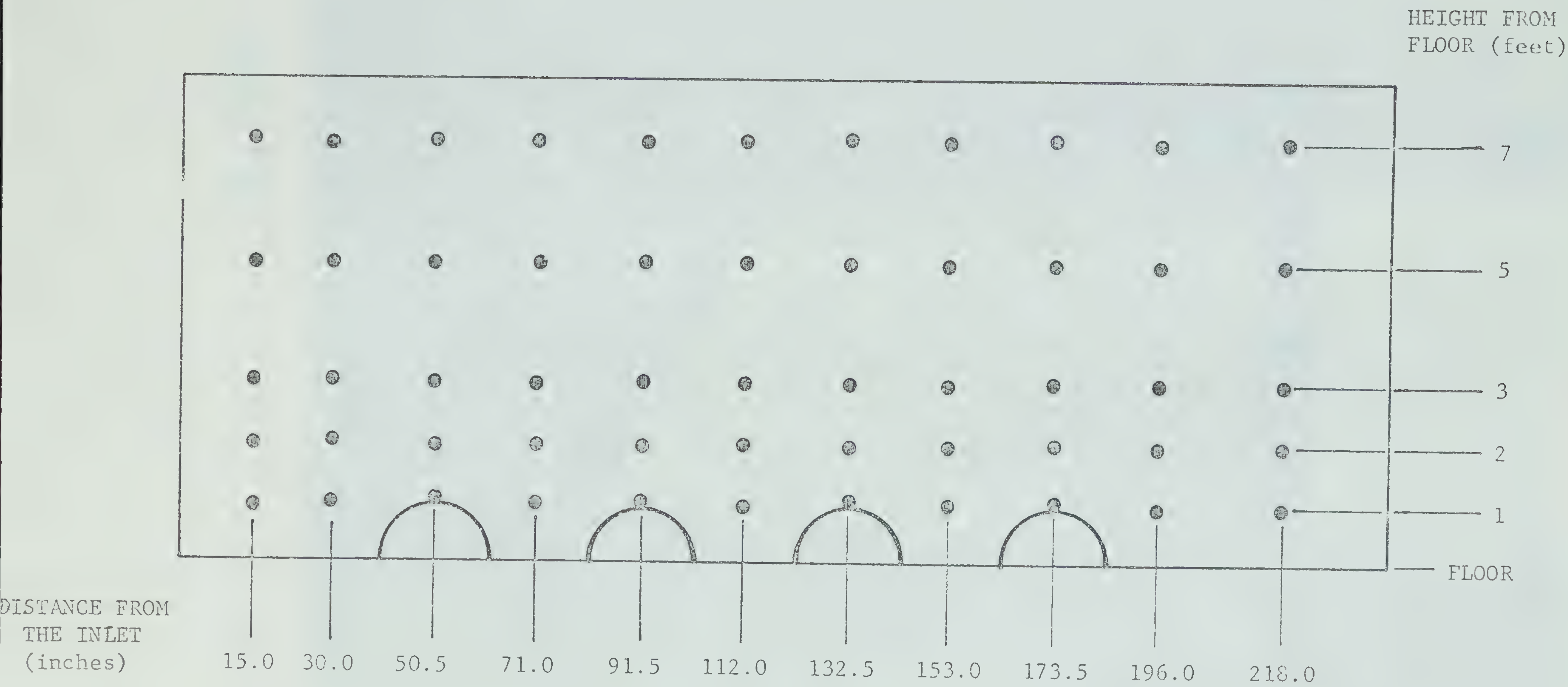

Figure 10. Longitudinal section showing the layout of the sampling points.

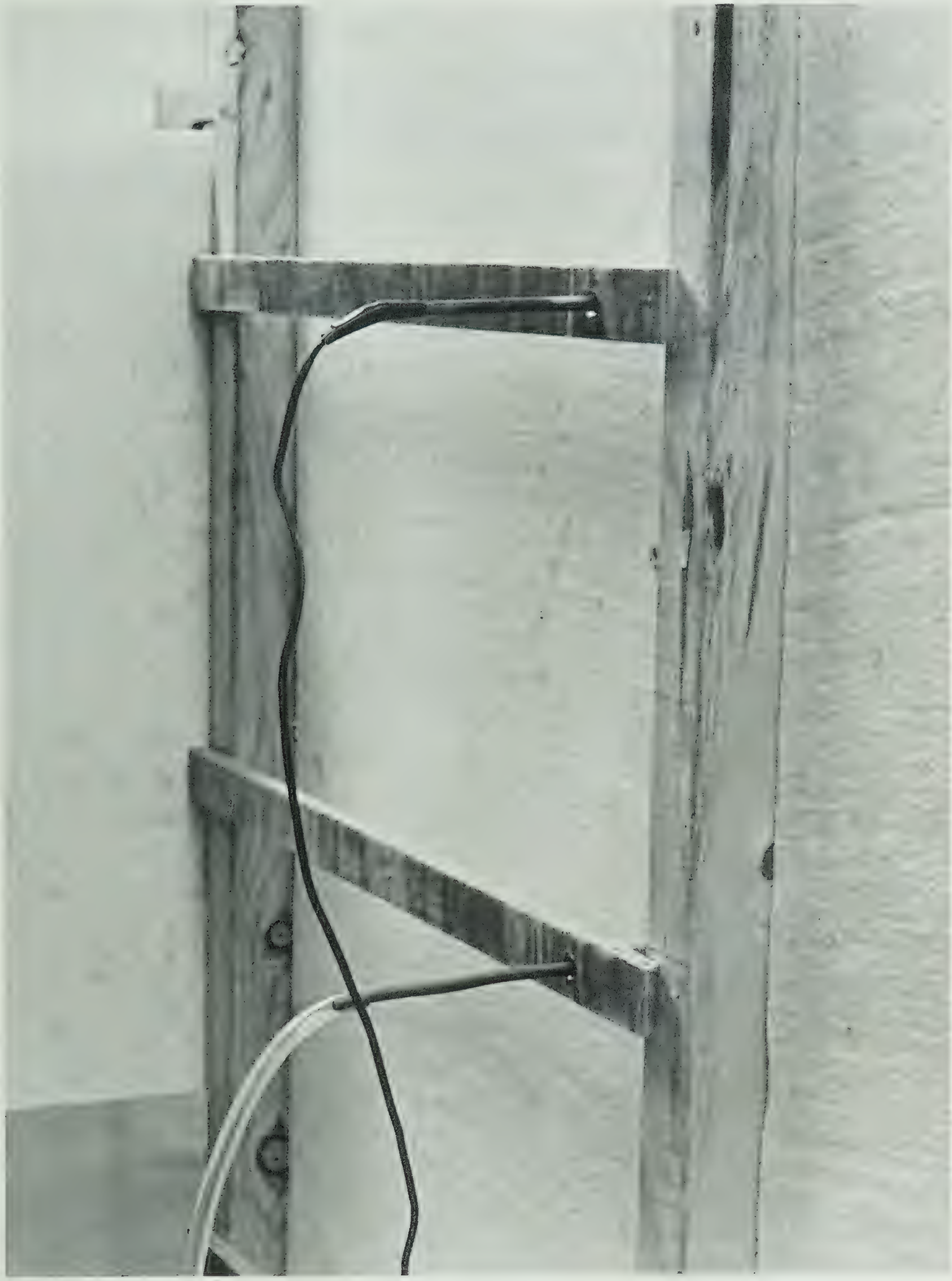

Figure 11: Gas and temperature probes inserted into two separate sampling holes.

were three replicates for each gas. A list of the independent variable combinations for each of the twelve trial runs in a replicate is given in Appendix II. During each replicate, the order of the trial runs was picked randomly.

5. DATA ANALYSIS AND RESULTS

5.1 Methods of Data Analysis

The analysis consisted of statistical procedures involving analysis of variance and multiple regression.

5.1.1 Independent Variables

The sources of variation, their levels and the codes used in the analysis are shown in table 1.

TABLE 1. LIST OF VARIABLES, THEIR CODES, AND THE LEVELS OF EACH USED.

Variable	Code	Levels	Comments
Ventilation rate	V	165 cfm 261 cfm 549 cfm	
Outlet height	O	19.0 inches 75.5 inches	
Heat condition	H	Isothermal	Neither heating elements nor air-conditioner in operation.
		Non-isothermal	Both the heating elements and air-conditioner operating.
Sampling height from floor	J	1 foot 2 feet 3 feet 5 feet 7 feet	
Distance from inlet (inches)	D	15.0, 30.0 50.5, 71.0 91.5,112.0 132.5,153.0 173.5,196.0 218.0	The distances 50.5, 91.5, 132.5, 173.5 correspond to centre lines of the points over the gas diffusion units.

5.1.2 Statistical Methods

For the analysis, gas concentrations in Appendices III and IV and temperatures found in Appendices V and VI were used. Analysis of variance techniques were used to determine which of the factors or factor interactions had a significant effect on gas concentrations. Multiple regression techniques were used to arrive at a prediction equation for gas concentrations in terms of the independent variables. University of Alberta Computing Centre library programmes were used for calculations involved in the analysis of variance (15) and multiple regression (17).

5.1.2.1 Analyses of Variance

The analyses of variance on the data were carried out on the basis of a split plot design with different combinations of ventilation rate (V), outlet height (O) and heat condition (H) in the whole plots and the distance from inlet (D) and height from floor (J) in the sub-plots.

5.1.2.2 Multiple Regression

Multiple regression analyses were carried out using the variables listed in table 1 as the independent variables and gas concentrations as the dependent variables.

5.2 Experiment I - Ammonia

The overall mean values for the different variables are presented to show the trends. Figure 12 shows the mean values of NH_3 concentrations for the three levels of ventilation rate. The concentrations were approximately in the ratio of 1:2:3 for ventilation rates 549 cfm, 261 cfm and 165 cfm respectively. Table 2 shows the effect of outlet height on the mean concentration of NH_3. The lower outlet height gave a slightly lower mean

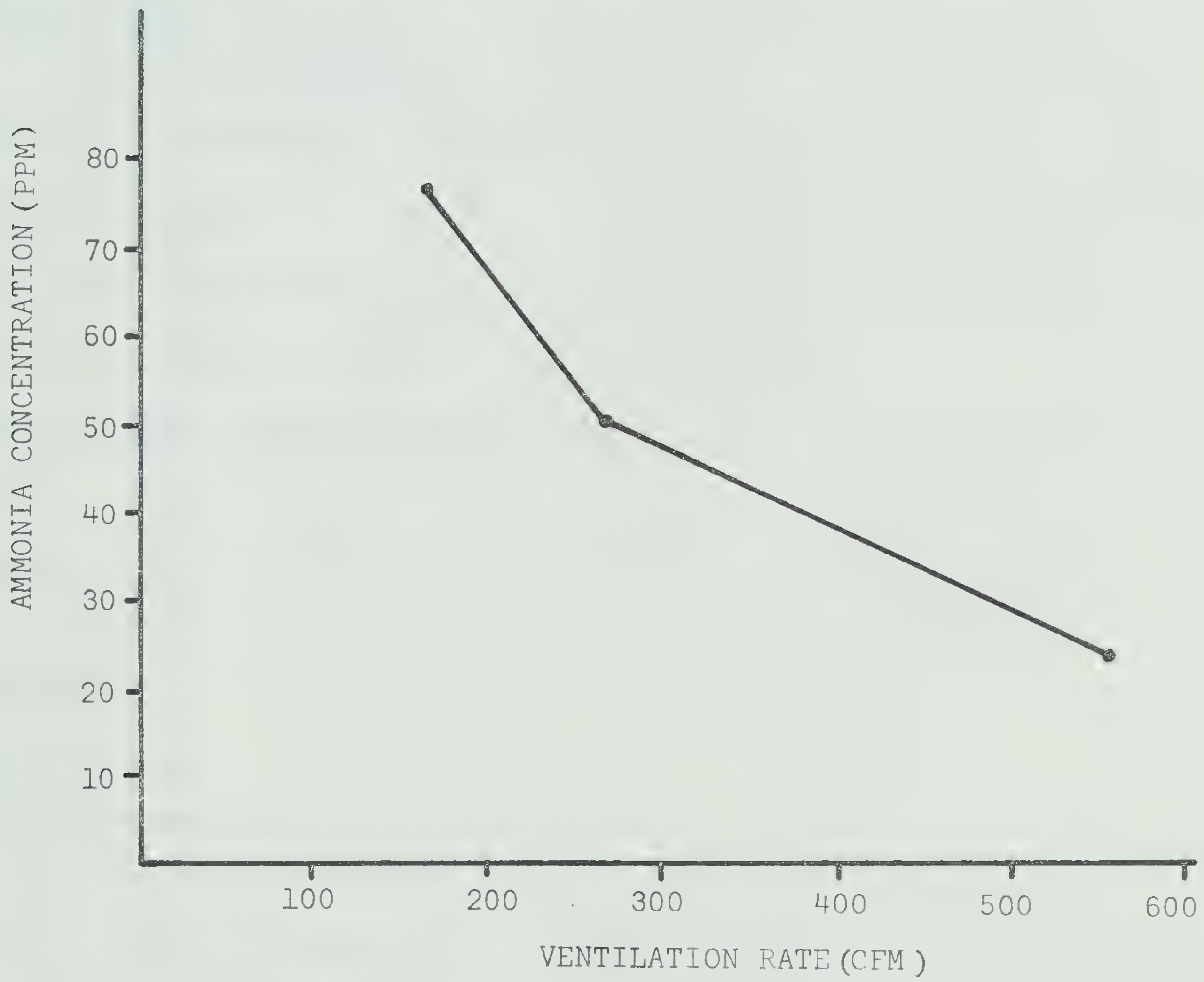

Figure 12. Graph illustrating the effect of ventilation rate on ammonia concentration.

concentration.

TABLE 2: MEAN CONCENTRATION OF AMMONIA AT BOTH LEVELS OF OUTLET HEIGHT (O).

Outlet Height (inches)	NH_3 Concentration (ppm)
19.0	49
75.5	53

The overall difference of the two heat conditions was 2 ppm (table 3). The effect of distance from the inlet is shown in figure 13. In general, there is a gradual increase in NH_3 concentration from inlet to outlet. It should be noted that the gas diffusion units are positioned 50.5, 91.5, 132.5, and 173.5 inches from the inlet.

TABLE 3: MEAN CONCENTRATIONS OF AMMONIA AT BOTH LEVELS OF HEAT CONDITION (H).

Heat Condition	NH_3 Concentration (ppm)
Isothermal	50
Non-isothermal	52

The effect of height from the floor (J) on the mean concentrations of NH_3 is shown in figure 14. The highest concentrations were at the 1 foot level. A slightly higher mean concentration was found at the 7 feet level than at the 5 feet level.

5.2.1 Analysis of Variance Results for Ammonia

The analysis of variance for concentrations of NH_3 are shown in table 4. The computed F-values in the analysis of variance table indicated that main effects due to ventilation rate, distance from inlet and height from floor were highly significant. Outlet height was significant at the

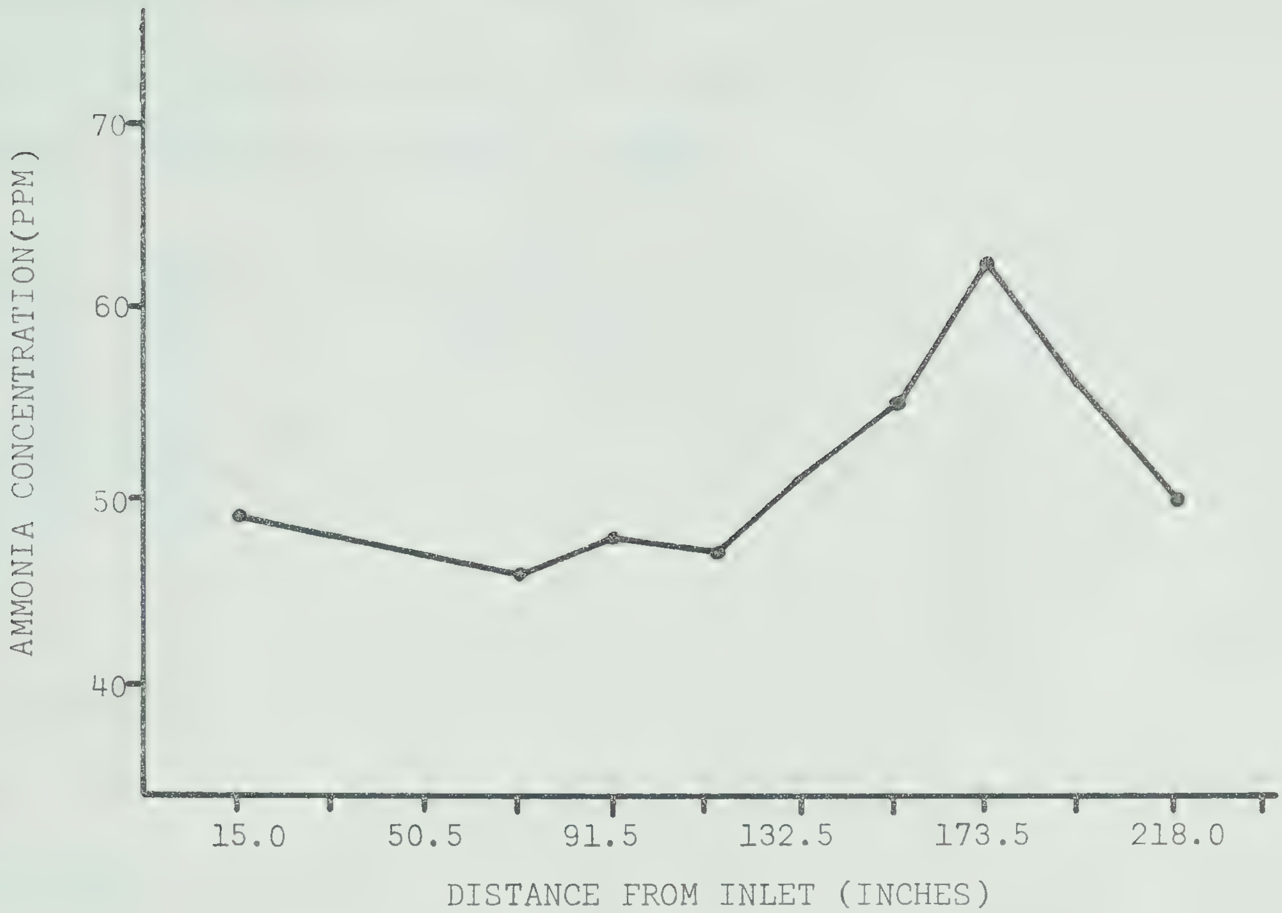

Figure 13. Graph illustrating the effect of distance from inlet on ammonia concentration.

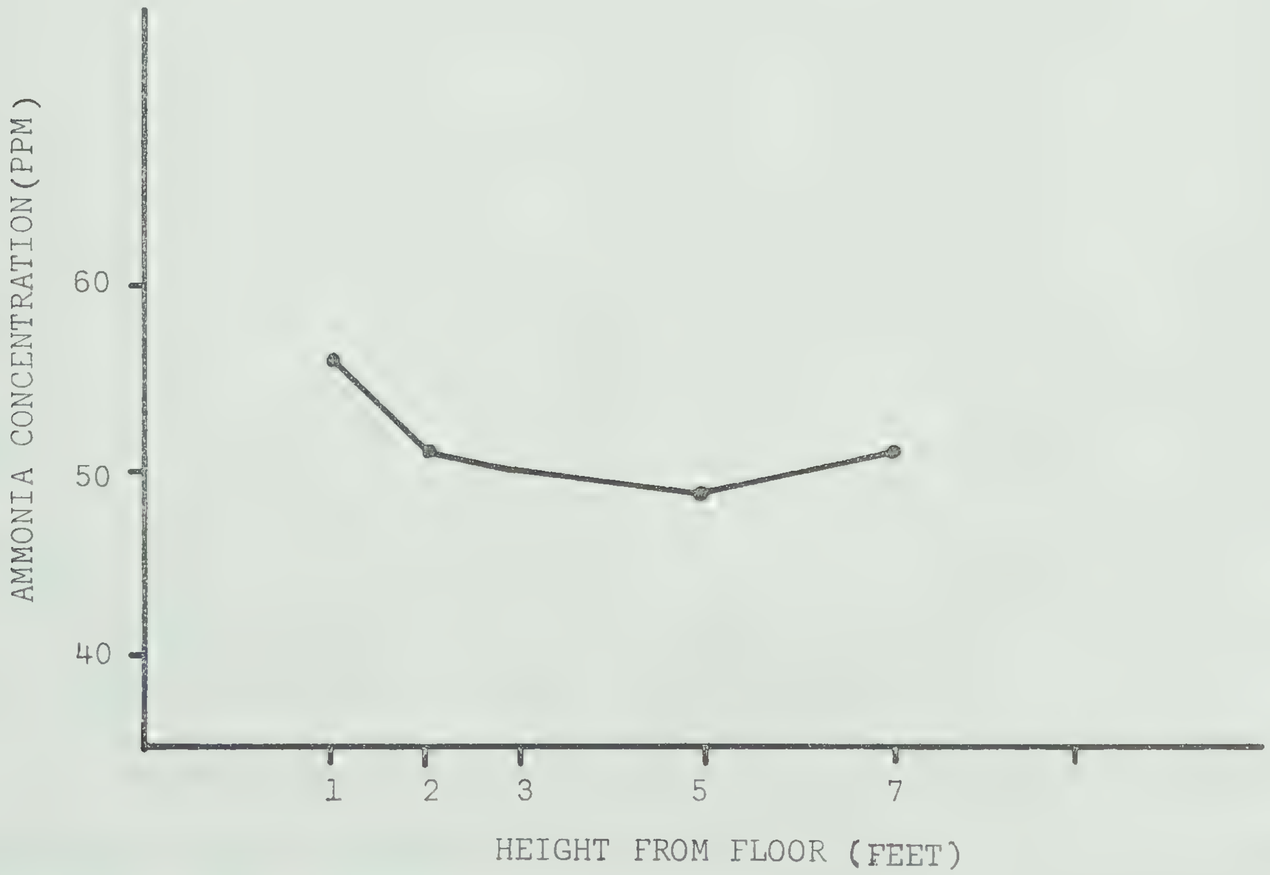

Figure 14. Graph illustrating the effect of height from floor on ammonia concentration.

.05 level. This indicated that variation in all of these factors gave significantly different NH_3 levels. With this gas, the two heat conditions used did not result in a statistical difference.

TABLE 4: ANALYSIS OF VARIANCE - AMMONIA.

Source of Variation	Degrees of Freedom	Mean Squares	F
V (Ventilation rates)	2	443350.0	332.49**
O (Outlet height)	1	6824.0	5.12*
H (Heat condition)	1	2736.7	2.05
VO	2	258.2	<1.00
VH	2	10547.5	7.91**
OH	1	10035.0	7.50*
VOH	2	168.3	<1.00
R (Replicates)	2		
ERROR (1)	22	1333.4	
D (Distance from inlet)	10	4773.7	76.58**
J (Height from floor)	4	2991.2	47.99**
DJ	40	1006.4	16.14**
DV	20	457.4	7.34**
JV	8	103.2	1.65
DJV	80	125.6	2.02**
DO	10	276.8	4.44**
JO	4	101.9	1.63
DJO	40	112.1	1.80**
DVO	20	230.8	3.70**
JVO	8	65.8	1.06
DH	10	516.9	8.29**
JH	4	1272.9	20.42**
DJH	40	225.6	3.62**
DVH	20	295.4	4.74**
JVH	8	100.3	1.61
DOH	10	357.7	5.74**
JOH	4	56.3	<1.00
ERROR (2)	1604	62.3	

* Significant at the .05 level of probability.
** Significant at the .01 level of probability.

A number of the interaction effects are interesting. The significant interactions of most relevance here are ventilation rate x heat condition (figure 15) and outlet height x heat condition (figure 16). Referring to

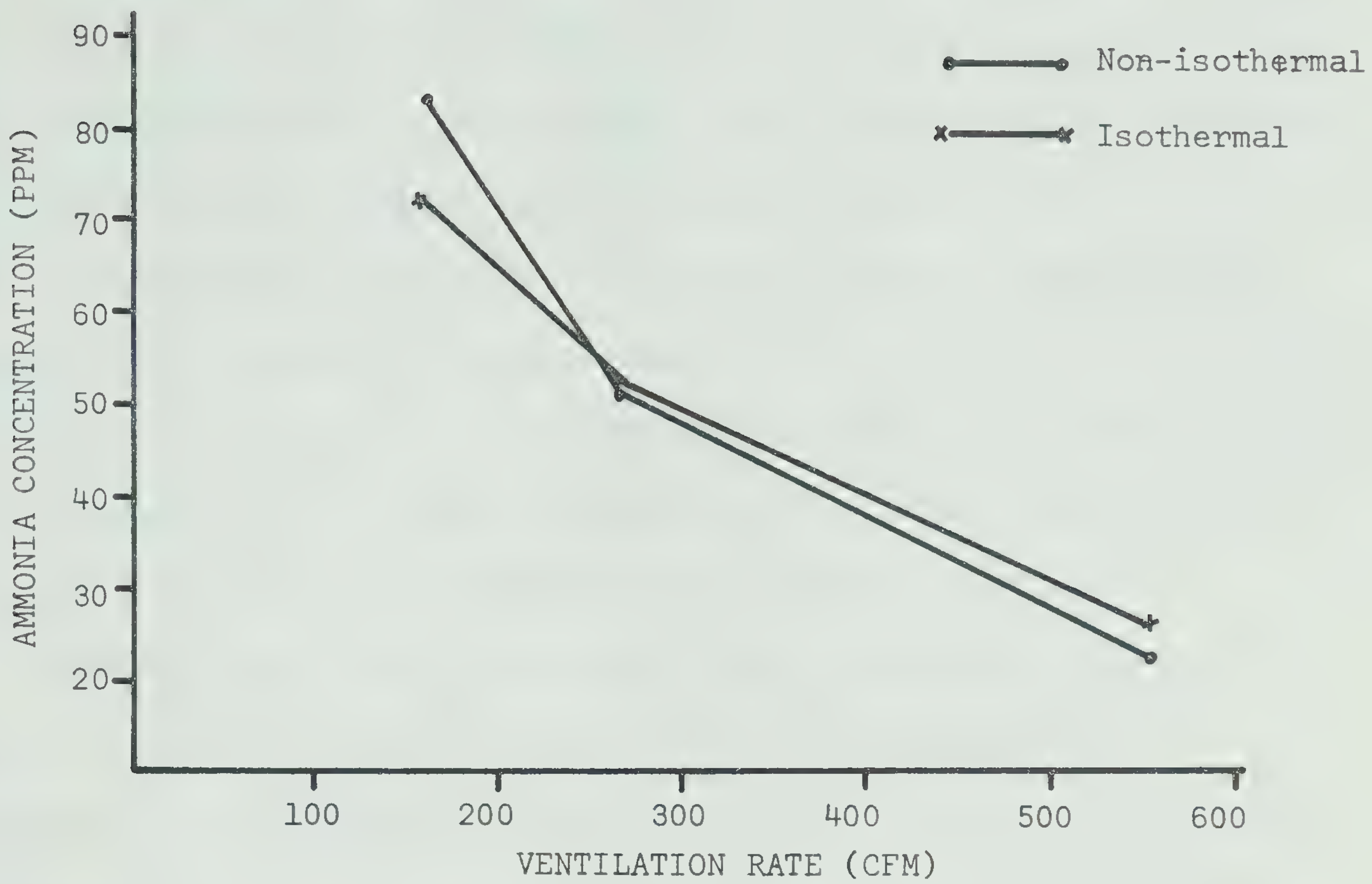

Figure 15. Graph illustrating the interaction of ventilation rate and heat condition (ammonia).

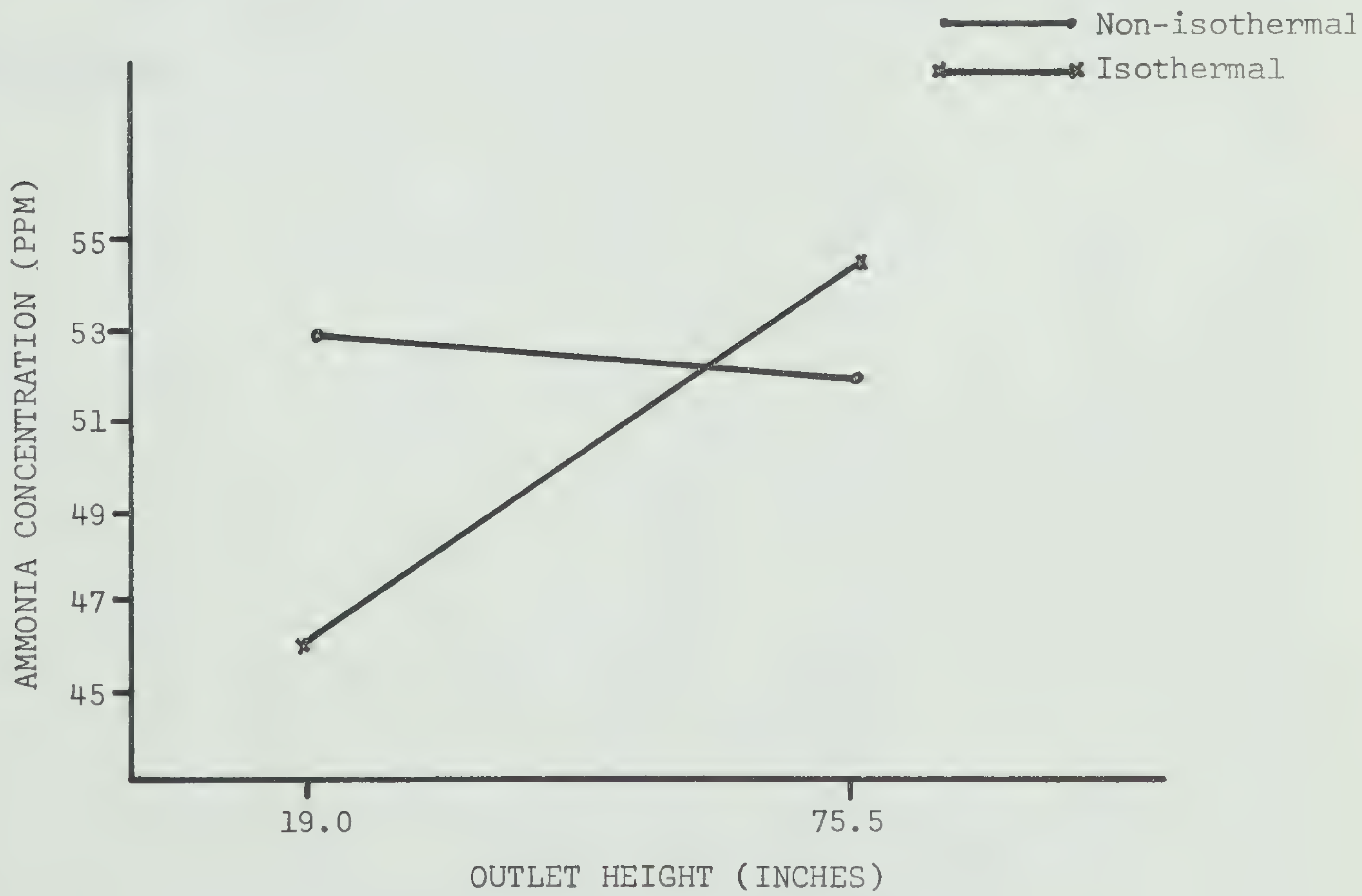

Figure 16. Graph illustrating the interaction of outlet height and heat condition (ammonia).

figure 15, it is seen that, at 165 cfm, the NH_3 concentration was higher under non-isothermal conditions while this situation was reversed at high ventilation rates. Figure 16 shows that under isothermal conditions the low level outlet resulted in the lower NH_3 concentration whereas under non-isothermal conditions the concentrations were approximately similar. The interaction between distance from the inlet and ventilation rate is shown in figure 17. The trend for the three ventilation rates is fairly similar. At the higher ventilation rate, there seems to be less variation in the gas concentration over the different values of D.

Figure 18 shows the interactions between ventilation rate and height from floor. Although this interaction is not statistically significant, the graphs are presented to show the variation that existed at the three ventilation rates over the different levels of height from floor as this variation, or lack of it, was a primary objective of the investigation.

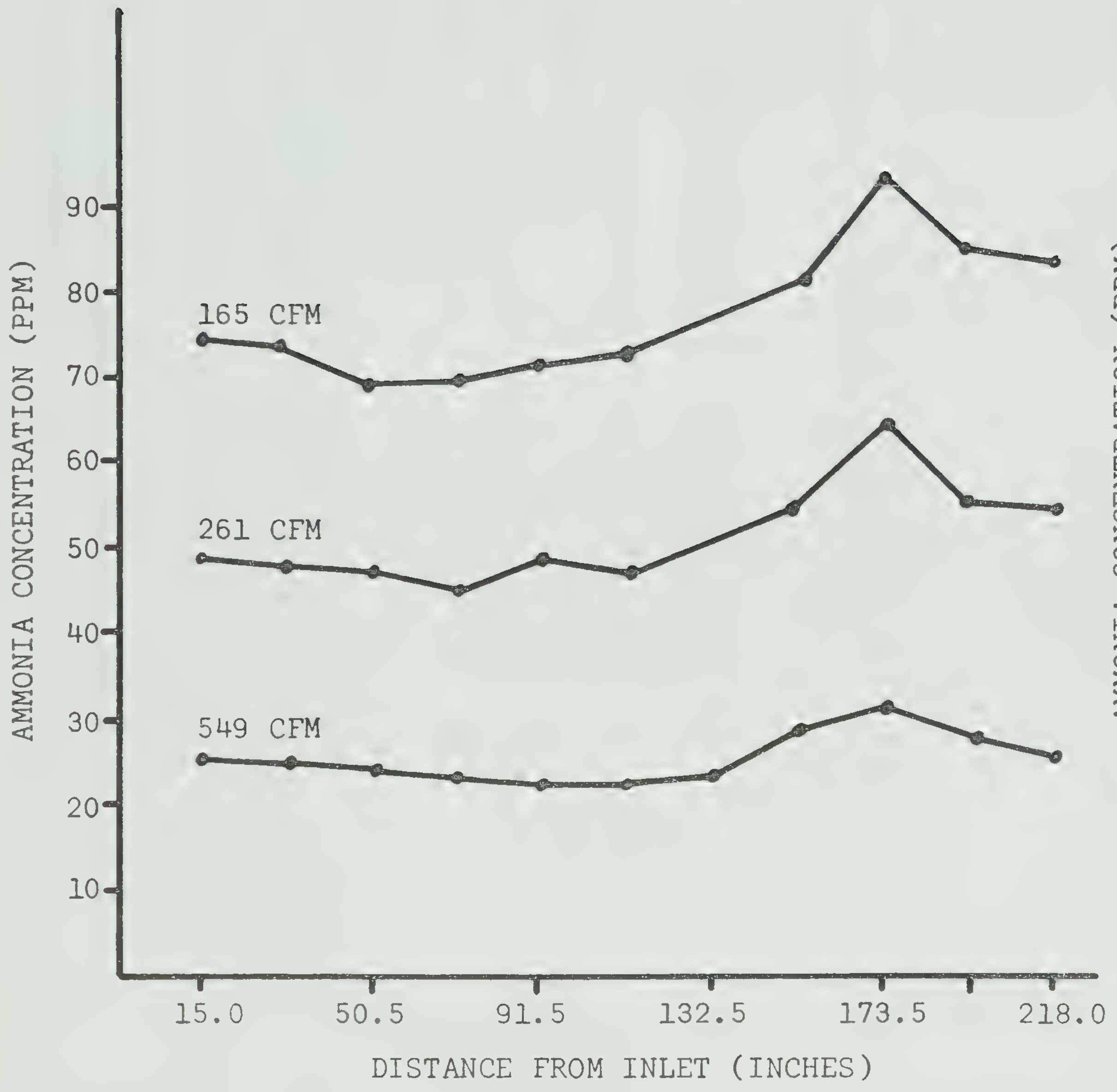

Figure 17. Graph illustrating interaction of distance from inlet and ventilation rate (ammonia).

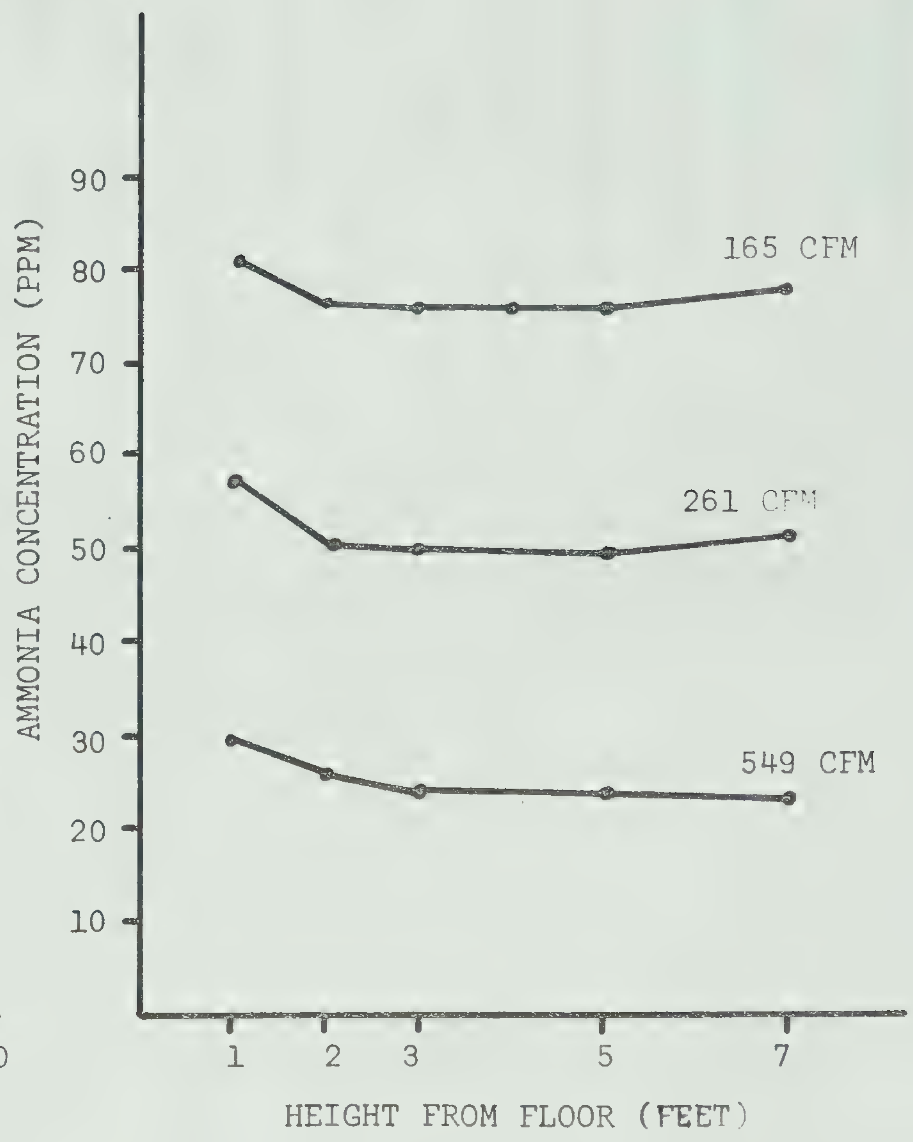

Figure 18. Graph illustrating the interaction of height from floor and ventilation rate (ammonia).

5.2.2 Temperature Data

The temperature data, recorded immediately after each gas sample was taken, are presented in Appendix V. Due to a malfunction in the temperature recorder during replicate 1, only those temperatures recorded for replicates 2 and 3 are presented.

Overall mean temperatures for the three ventilation rates are plotted in figure 19. Table 5 shows the effect of outlet height on the mean temperature recorded. It is seen that little difference existed between the two outlet heights.

TABLE 5: MEAN TEMPERATURES AT BOTH LEVELS OF OUTLET HEIGHT (AMMONIA).

Outlet Height (inches)	Temperature (^{o}F)
19.0	73.0
75.5	72.9

The overall difference between the two heat conditions is 2.1^{o}F (table 6).

TABLE 6: MEAN TEMPERATURES AT BOTH LEVELS OF HEAT CONDITION (AMMONIA).

Heat Condition	Temperature (^{o}F)
Isothermal	71.9
Non-isothermal	74.0

The effect of distance from the inlet is shown in figure 20 and the effect of height from floor in figure 21. Temperature variation for both of these factors is seen to be similar to the variation of NH_3 concentrations. The effect on temperature of the location of the heating elements in the

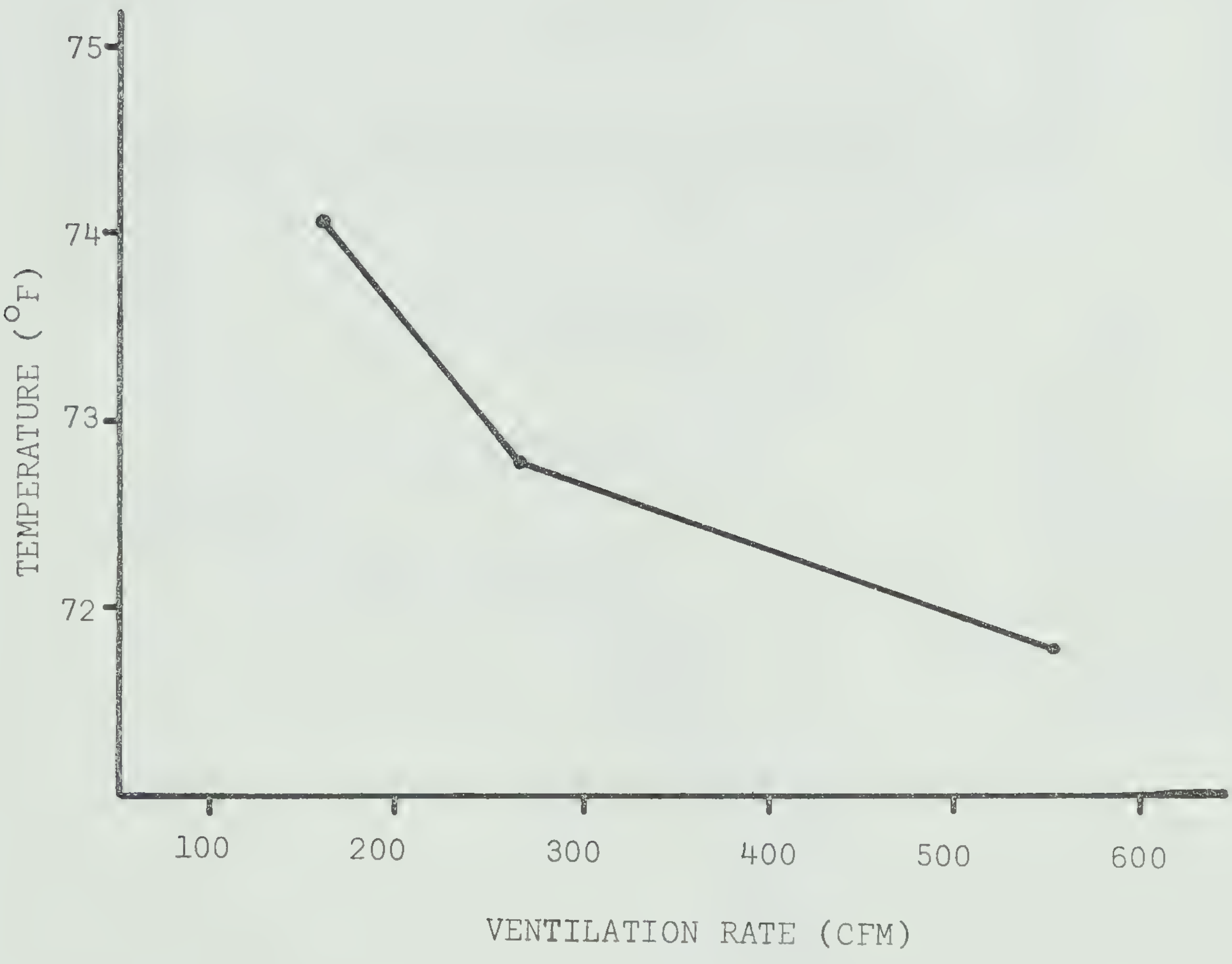

Figure 19. Graph illustrating the effect of ventilation rate on temperature (ammonia).

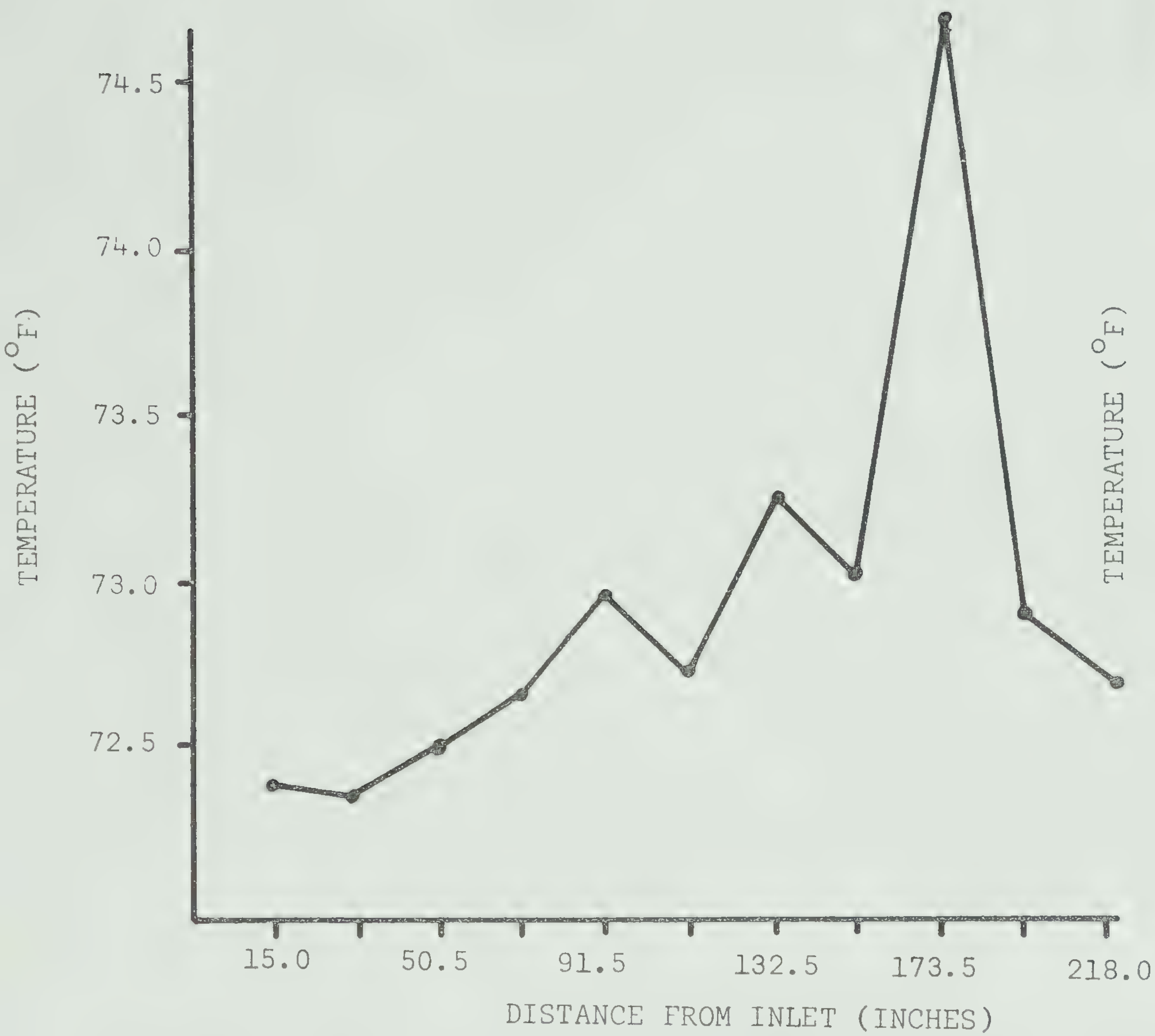

Figure 20. Graph illustrating the effect of distance from inlet on temperature (ammonia).

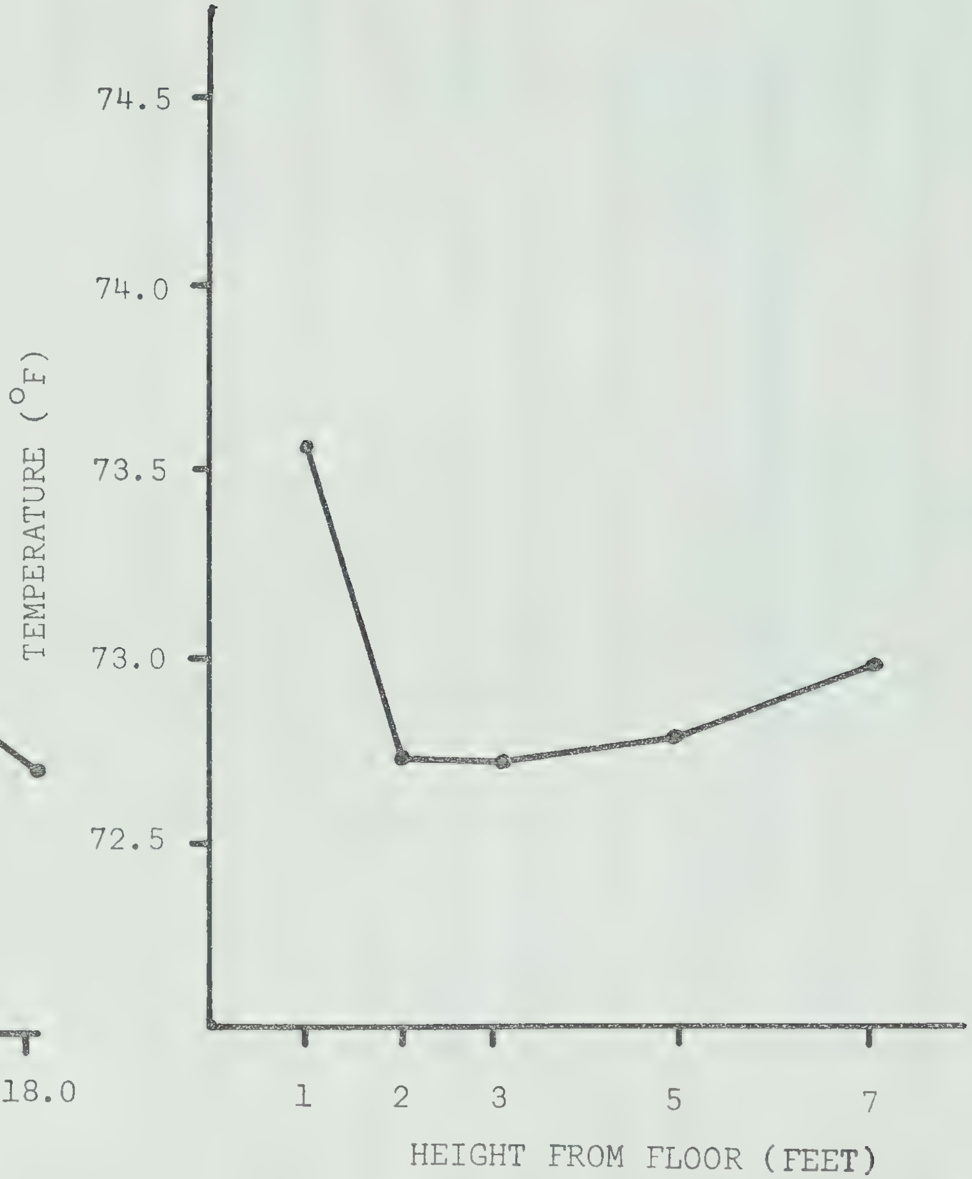

Figure 21. Graph illustrating the effect of height from floor on temperature (ammonia).

gas diffusion units at 173.5, 132.5, and 91.5 inches from the inlet is evidenced by the peaks at these points (figure 20). No effect of the heating elements on temperature at 50.5 inches from the inlet is obvious.

5.2.2.1 Analysis of Variance Results for Temperature

The analysis of variance results for temperature are shown in table 7. Of the main effects, only ventilation rate and heat condition are significant. No significant difference was found between the two outlet heights. Differences between the two replicates analysed were found to be significant at the .05 probability level. This overall difference recorded was very small (0.2°F) and is not considered important. The significant interaction ventilation rate x heat condition indicates that the effect of ventilation rate on temperature is different for the two heat conditions.

TABLE 7: ANALYSIS OF VARIANCE-TEMPERATURE (AMMONIA).

Source of Variation	Degrees of Freedom	Mean Squares	F
V (Ventilation rate)	2	635.52	257.27**
O (Outlet height)	1	0.14	<1
H (Heat condition)	1	1469.40	594.85**
VO	2	8.97	3.63
VH	2	501.75	203.12**
OH	1	7.38	2.98
VOH	2	0.90	<1
R (Replicates)	1	17.89	7.24*
ERROR (1)	11	2.47	
D (Distance from inlet)	10	52.64	80.48**
J (Height from floor)	4	32.00	48.93**
DJ	40	25.77	39.41**
DV	20	2.69	4.11**
JV	8	3.03	4.62**
DJV	80	2.07	3.17**
DO	10	1.31	2.00*
JO	4	0.48	<1
DJO	40	0.39	<1
DVO	20	0.26	<1
JVO	8	0.09	<1
DH	10	50.04	76.51**
JH	4	34.78	53.18**
DJH	40	24.58	37.59**
DVH	20	2.61	3.99**
JVH	8	2.94	4.49**
DOH	10	0.87	1.33
JOH	4	0.87	1.33
ERROR (2)	956	0.66	

* Significant at the .05 level of probability.
** Significant at the .01 level of probability.

5.3 Experiment II - Carbon Dioxide

The overall means of CO_2 concentrations for the different ventilation rates are plotted in figure 22. The three concentrations are approximately in the ratio 1:2:3.

Carbon dioxide concentrations for the two outlet heights are shown in table 8. As was the case with NH_3 concentrations, the overall mean for the lower outlet height was less than that for the upper outlet.

TABLE 8: MEAN CONCENTRATIONS OF CARBON DIOXIDE AT BOTH LEVELS OF OUTLET HEIGHT (O).

Outlet Height	CO_2 Concentration (ppm)
19.0	910
910	980

The overall concentrations of CO_2 for both levels of heat condition are given in table 9. As in Experiment I, the mean CO_2 concentration was higher for the non-isothermal condition.

TABLE 9: MEAN CONCENTRATIONS OF CARBON DIOXIDE AT BOTH LEVELS OF HEAT CONDITION (H).

Heat Condition	CO_2 Concentration (ppm)
Isothermal	910
Non-isothermal	980

The overall mean CO_2 concentration for all eleven distances from the inlet (figure 23) followed the same trend as the NH_3 concentrations. The difference between the highest and lowest value was found to be 280 ppm. The effect of height from floor (J) on the mean is shown in figure 24. In this case, as with NH_3, the highest concentrations occurred

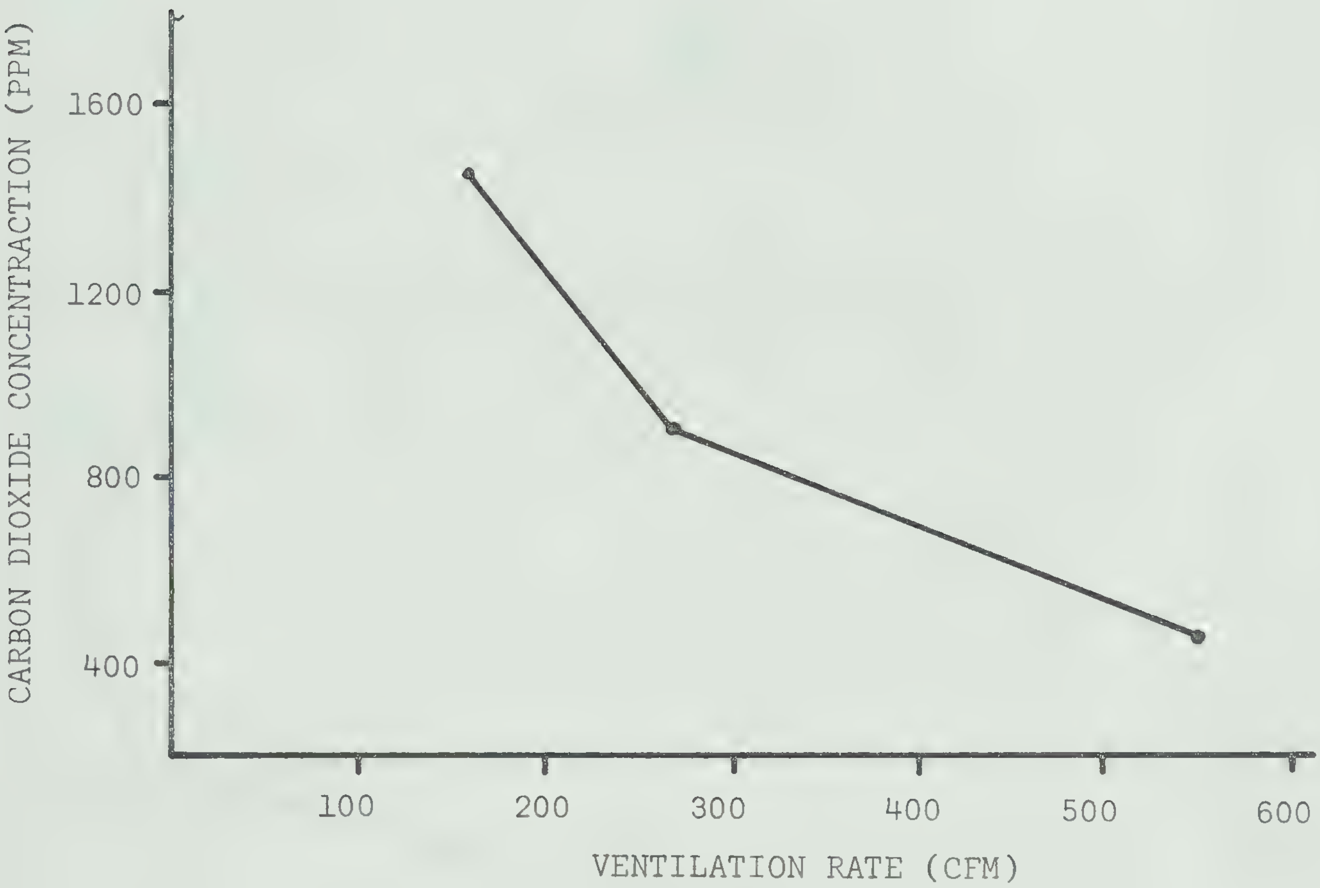

Figure 22. Graph illustrating the effect of ventilation rate on carbon dioxide concentration.

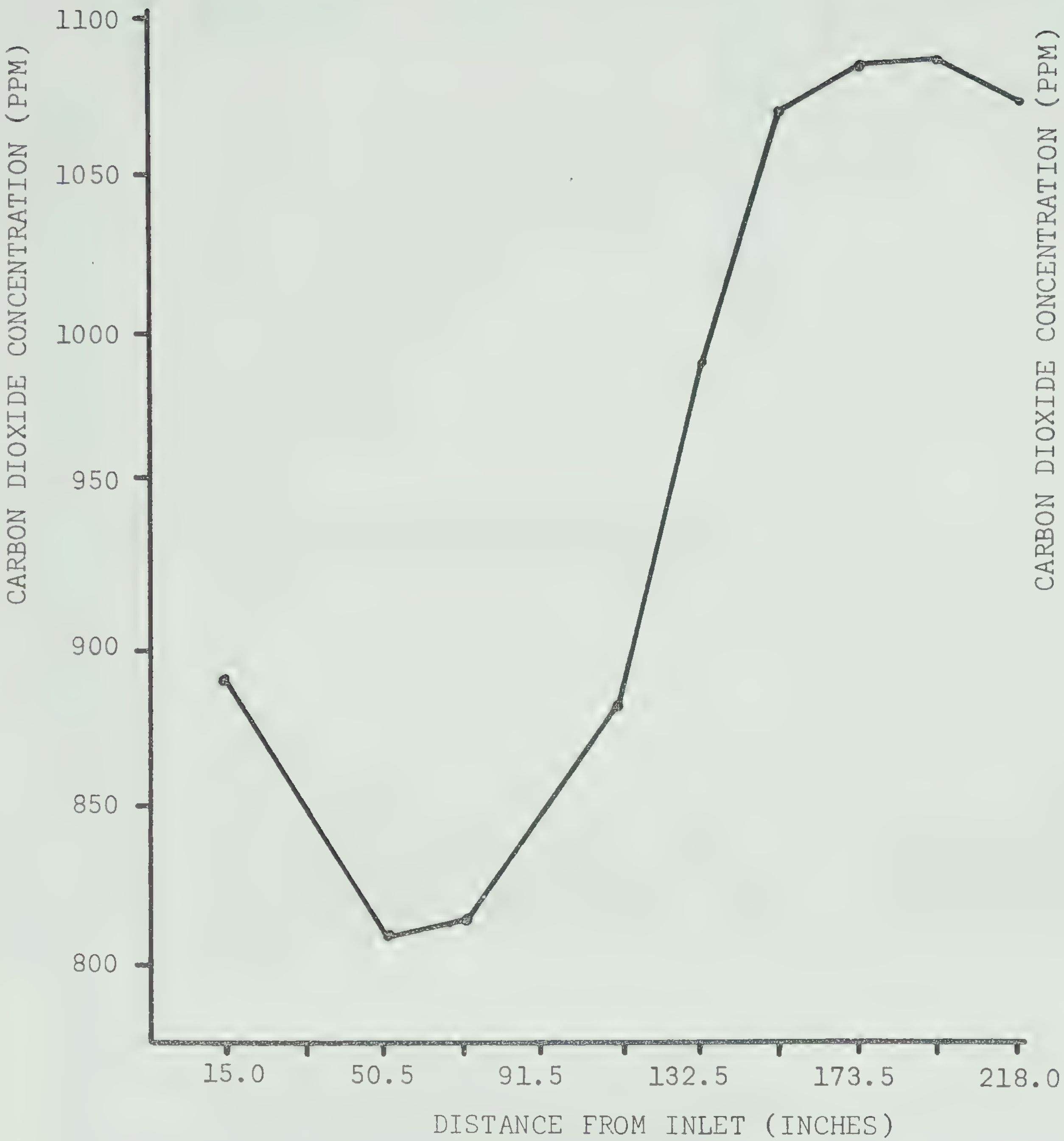

Figure 23. Graph illustrating the effect of distance from inlet on carbon dioxide concentration.

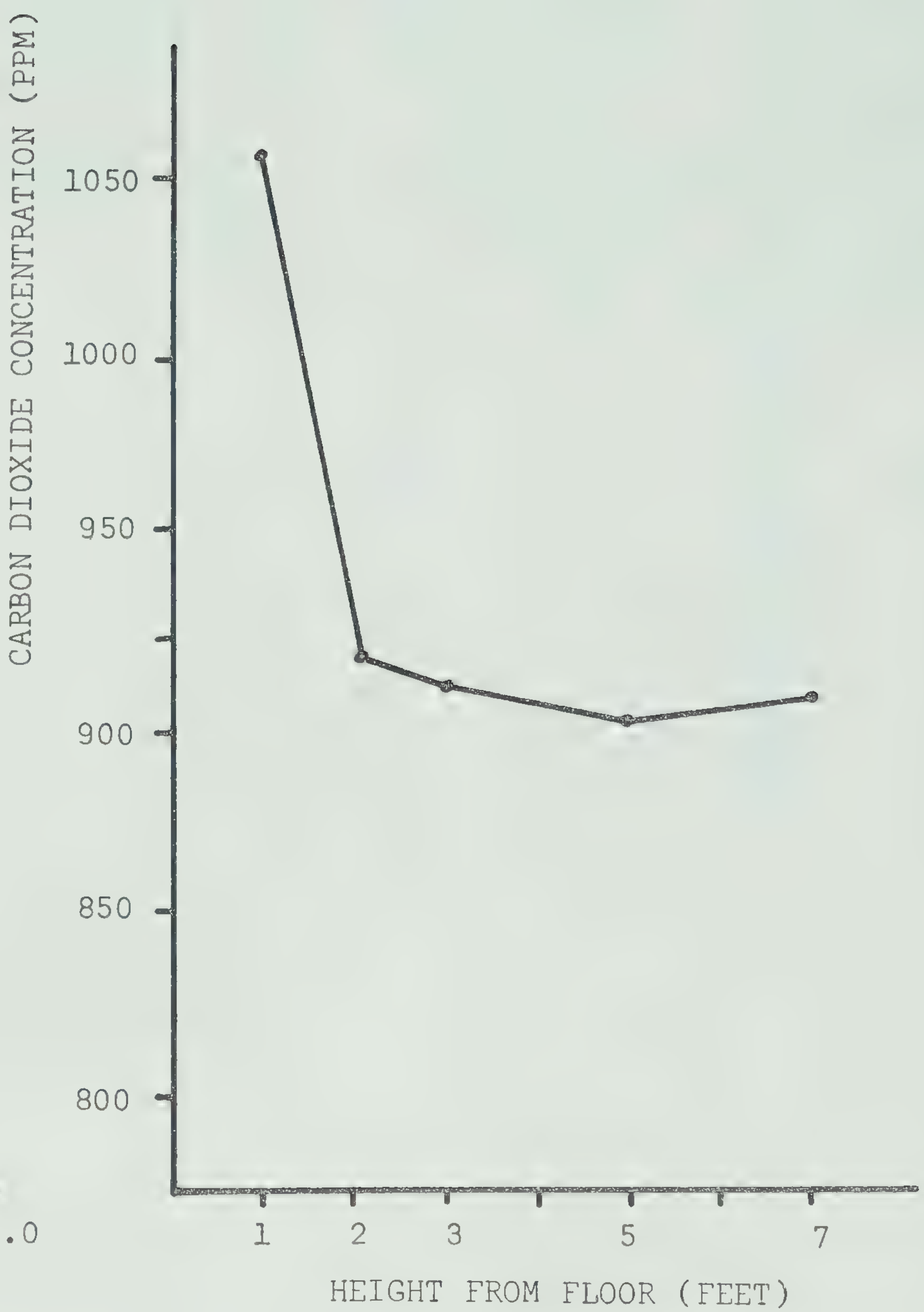

Figure 24. Graph illustrating the effect of height from floor on carbon dioxide concentration.

at one foot from floor level while the concentration at 7 feet is slightly higher than at 5 feet.

5.3.1 Analysis of Variance Results for Carbon Dioxide

The analysis of variance for concentrations of CO_2 is shown in table 10. In this case, all the main effects (ventilation rate, outlet height, heat condition, distance from the inlet and height from the floor) are highly significant.

TABLE 10. ANALYSIS OF VARIANCE - CARBON DIOXIDE.

Source of Variation	Degrees of Freedom	Mean Squares	F
V (Ventilation rate)	2	163,230,000	844.35**
O (Outlet height)	1	2,009,700	10.39**
H (Heat condition)	1	2,573,400	13.31**
VO	2	1,559,500	8.06**
VH	2	2,555,800	13.22**
OH	1	3,652,300	18.89**
VOH	2	2,624,700	13.57**
R (Replicates)	2	152,430	<1.00
ERROR (1)	22	193,320	
D (Distance from inlet)	10	2,297,800	197.03**
J (Height from floor)	4	1,686,600	144.62**
DJ	40	305,740	26.21**
DV	20	292,640	25.09**
JV	8	124,190	10.64**
DJV	80	56,626	4.85**
DO	10	142,950	12.25**
JO	4	43,723	3.74**
DJO	40	15,832	1.35
DVO	20	14,409	1.23
JVO	8	110,230	9.45**
DH	10	339,860	29.14**
JH	4	1,051,100	90.13**
DJH	40	92,822	7.95**
DVH	20	176,130	15.10**
JVH	8	247,037	21.18**
DOH	10	88,581	7.59**
JOH	4	19,390	1.66
ERROR (2)	1604	11,662	

** Significant at the .01 level of probability.

The interactions plotted for NH_3 in experiment 1 are also plotted for this experiment (figures 25,26,27 and 28). The ventilation rate x heat condition interaction (figure 25) follows the same trend as found for NH_3 (figure 15). Increasing ventilation rate changed the relationship between the mean concentration for non-isothermal and isothermal conditions. The outlet height x heat condition interaction (figure 26) shows that low level outlet points reduce the concentration considerably under isothermal conditions. Under non-isothermal conditions,the effect of low level extraction was negligible.

The interactions ventilation rate x distance from inlet (DV) and ventilation rate x height from floor (VJ) are shown in figures 27 and 28 respectively. These show the general trend of concentration variations over the three ventilation rates at different heights and distance from the inlet.

The similarity in the concentration variations of both gases over all the interactions indicates that the distribution pattern for heavy and light gases does not differ.

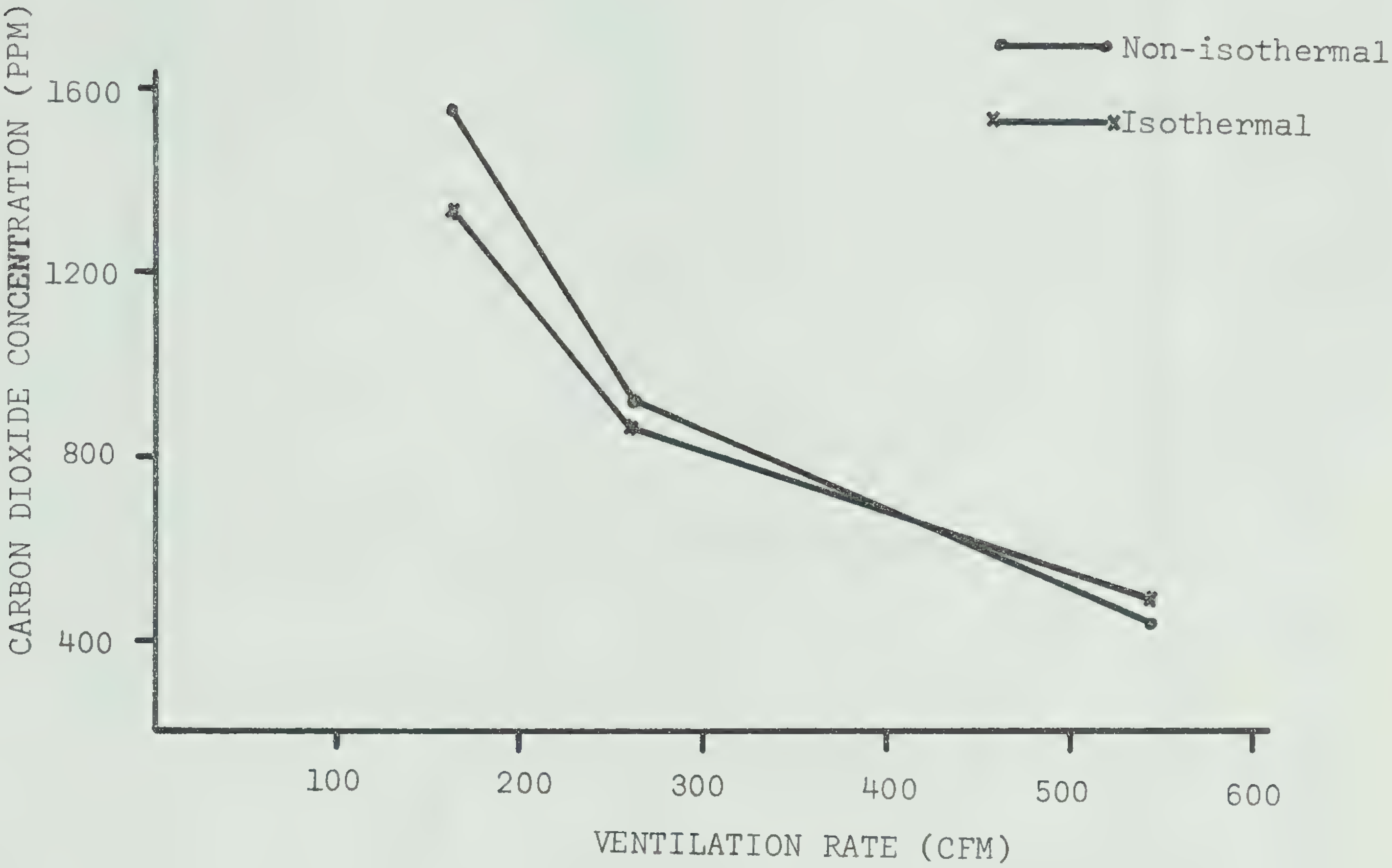

Figure 25. Graph illustrating the interaction of ventilation rate and heat condition (carbon dioxide).

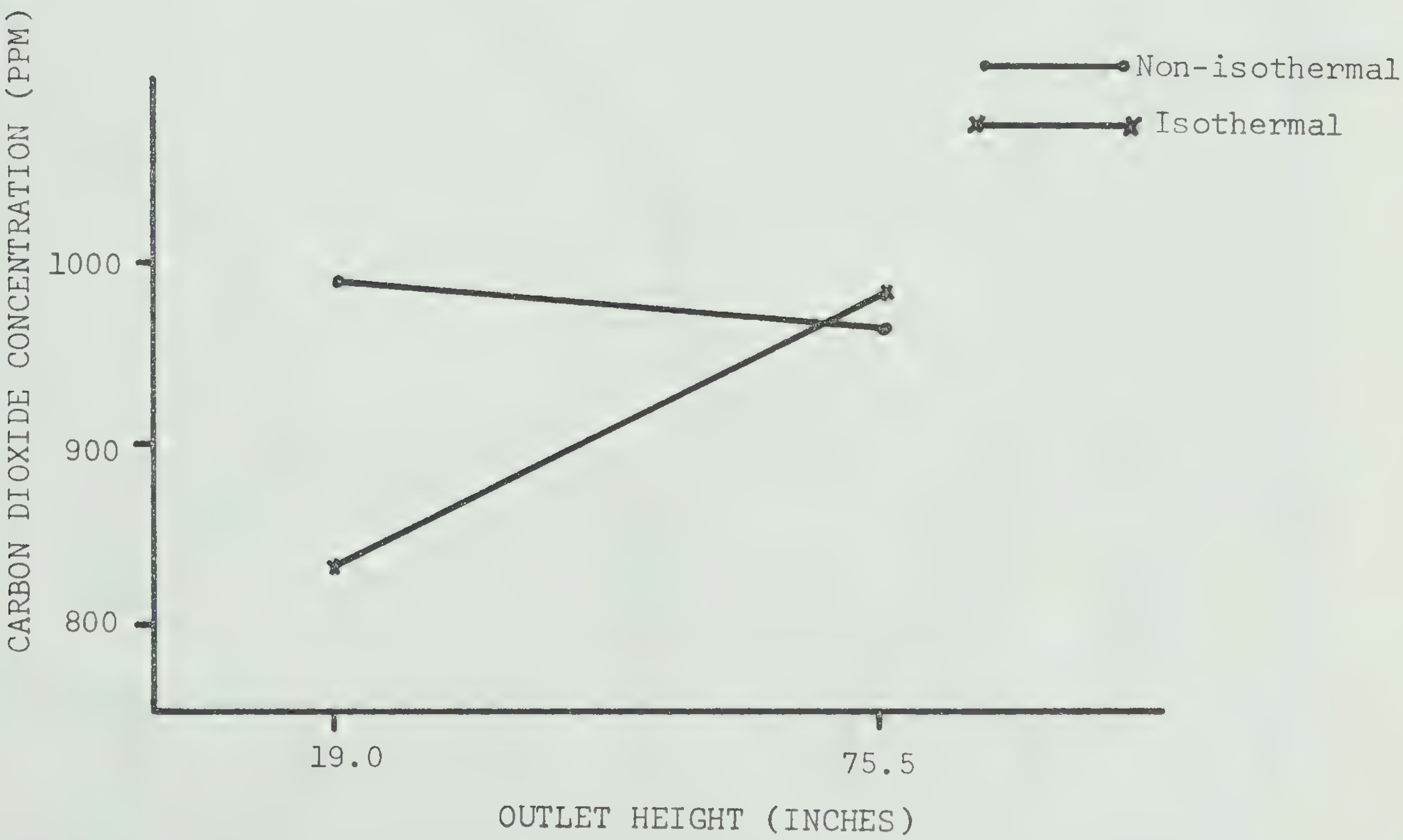

Figure 26. Graph illustrating the interaction of outlet height and heat condition (carbon dioxide).

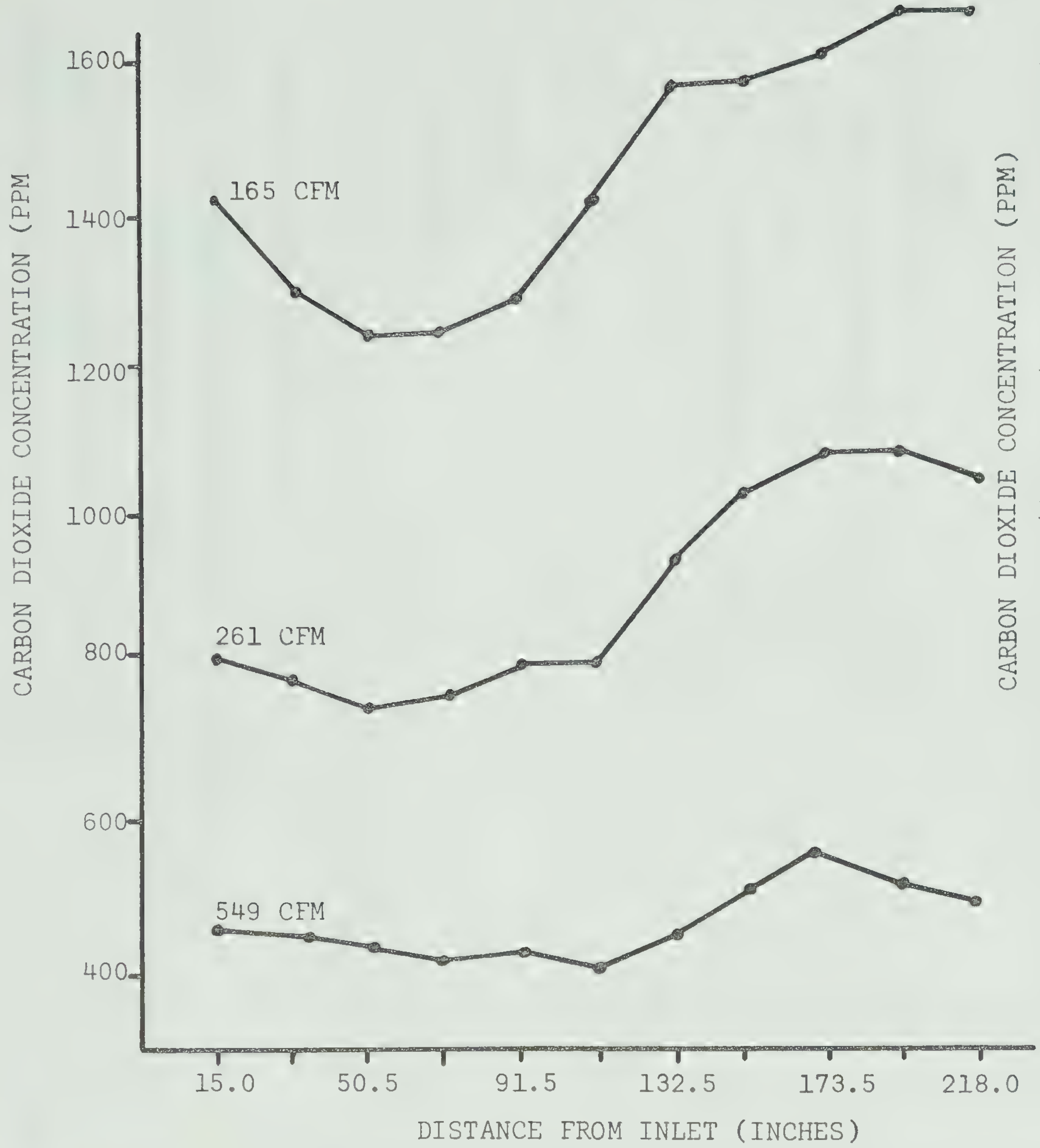

Figure 27. Graph illustrating the interaction of distance from inlet and ventilation rate (carbon dioxide)

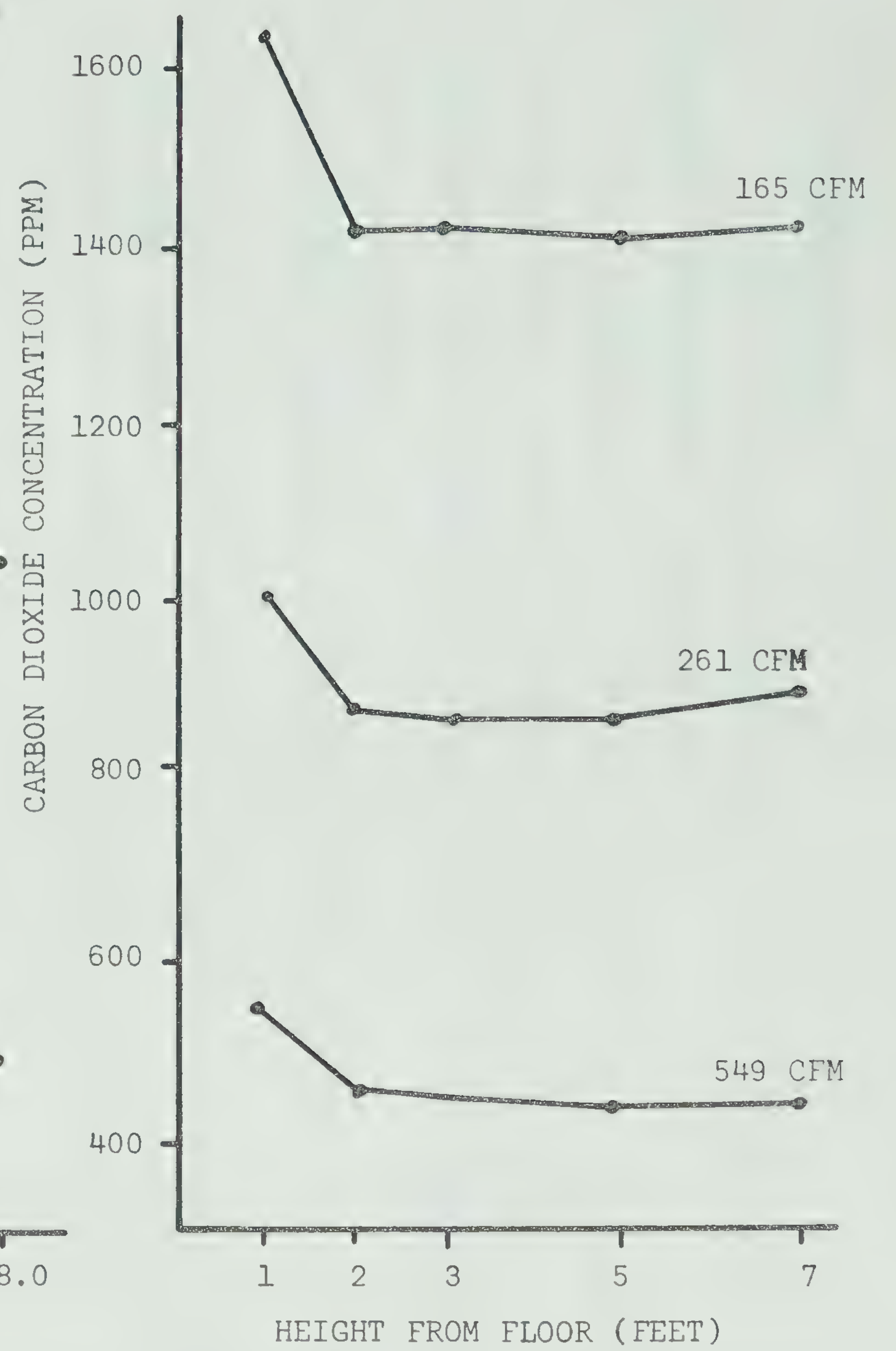

Figure 28. Graph illustrating the interaction of height from floor and ventilation rate (carbon dioxide).

5.3.2 Temperature Data

Temperature data recorded for the three replicates of this experiment are presented in Appendix VI.

Overall temperatures for the three ventilation rates are plotted in figure 29. Table 11 shows the effect of outlet height on the mean temperatures. As with Experiment I, little difference was found between the two outlet heights.

TABLE 11: MEAN TEMPERATURES AT BOTH LEVELS OF OUTLET HEIGHT (CARBON DIOXIDE).

Outlet Height (inches)	Temperature (°F)
19.0	73.8
75.5	73.5

The overall temperature difference between the two heat conditions is 2.2°F (table 12), compared with 2.1°F in the case of experiment I.

TABLE 12: MEAN TEMPERATURES AT BOTH LEVELS OF HEAT CONDITION (CARBON DIOXIDE).

Heat Condition	Temperature (°F)
Isothermal	72.6
Non-isothermal	74.8

The effect of distance from the inlet is shown in figure 30 and the effect of height from the floor in figure 31.

5.3.2.1 Analysis of Variance Results for Temperature

The analysis of variance results for temperature are shown in table 13. In the main plots, ventilation rate and heat condition were found to be significant at the .01 level, while the outlet height showed

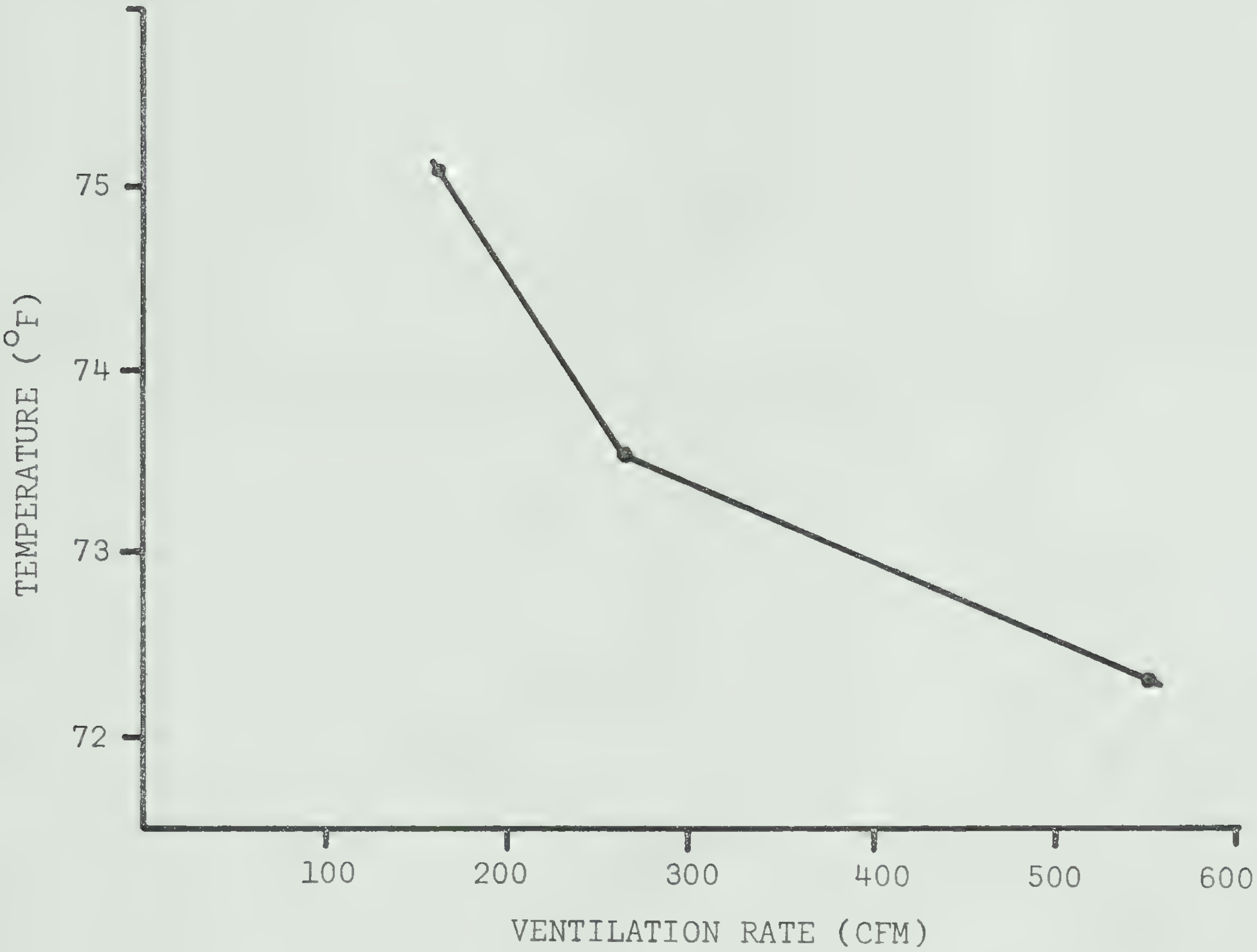

Figure 29. Graph illustrating the effect of ventilation rate on temperature (carbon dioxide).

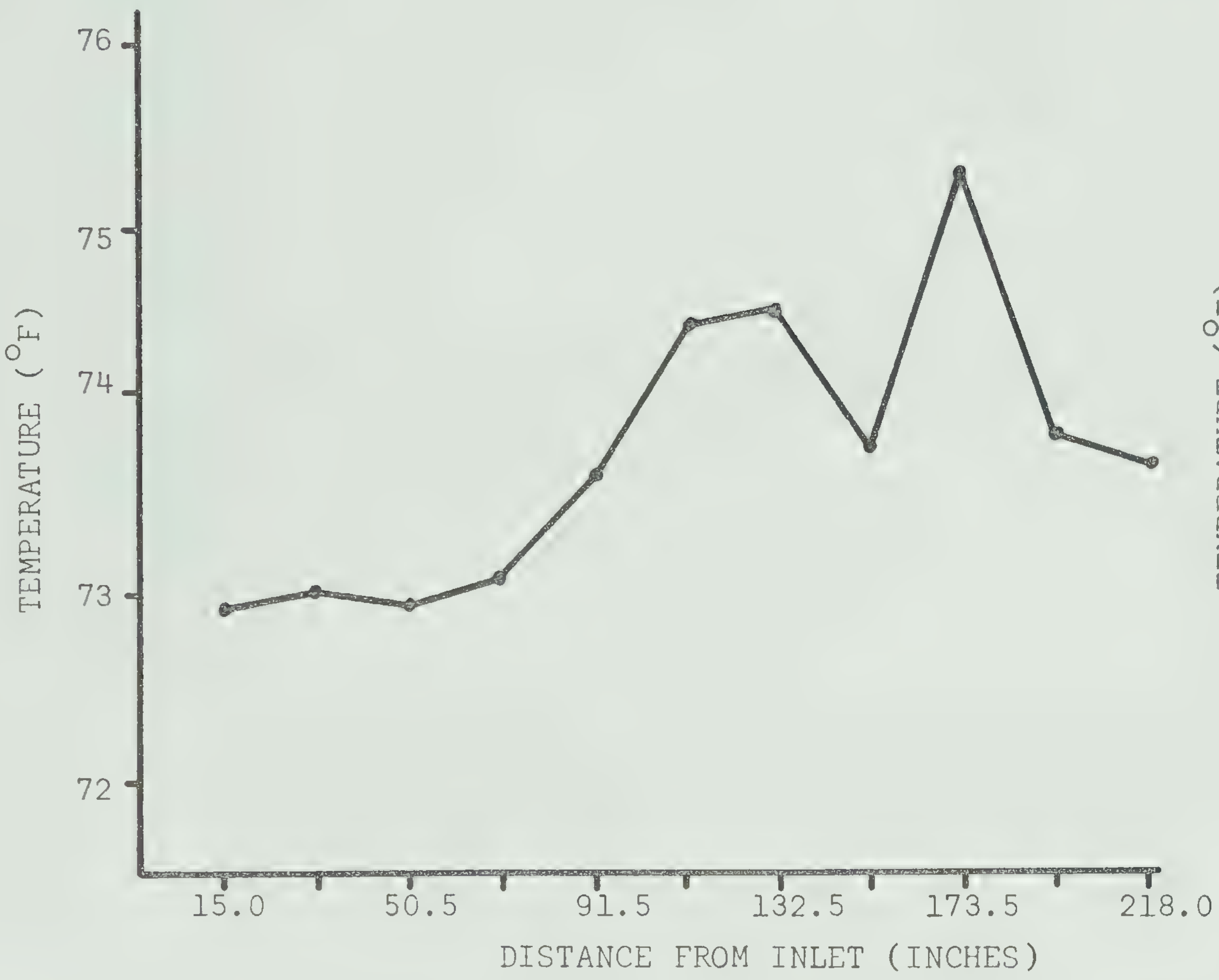

Figure 30. Graph illustrating the effect of distance from inlet on temperature (carbon dioxide).

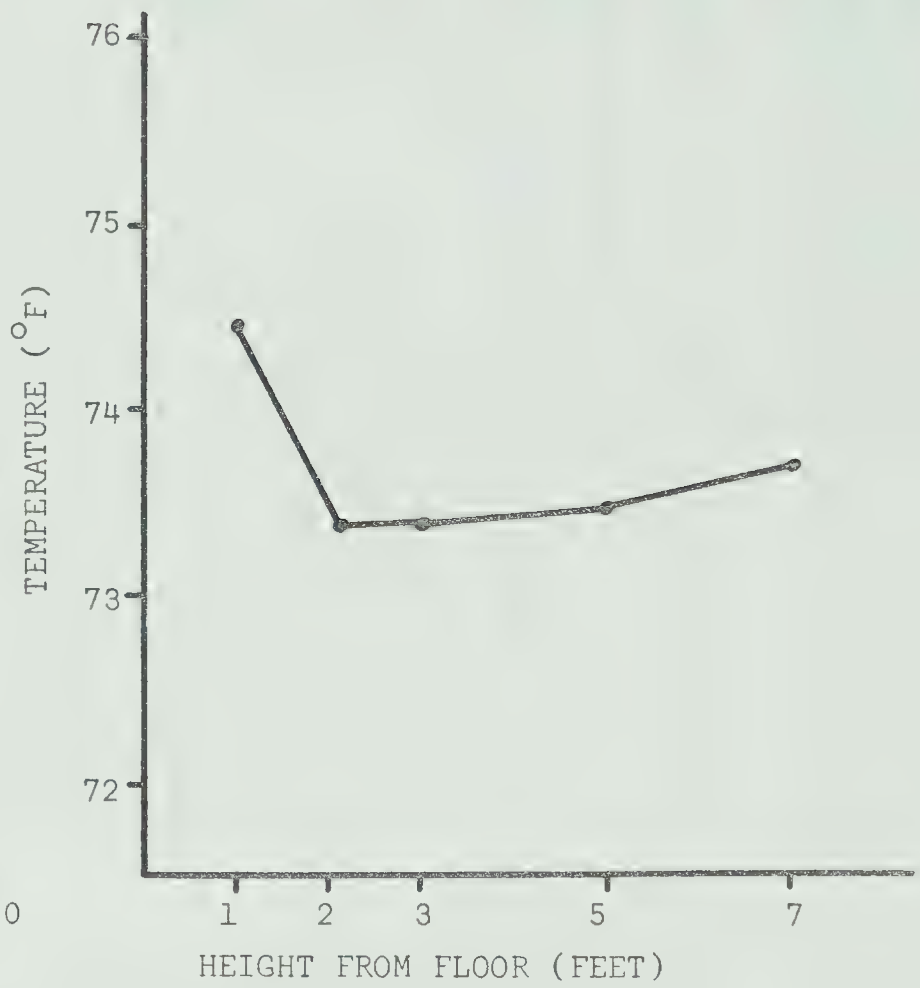

Figure 31. Graph illustrating the effect of height from floor on temperature (carbon dioxide).

significance at the .05 probability level. As in the case of temperature data for experiment 1, the ventilation rate x heat condition interaction was significant.

In the sub-plots, the distance from inlet and height from floor showed significant differences.

TABLE 13: ANALYSIS OF VARIANCE-TEMPERATURE (CARBON DIOXIDE).

Source of Variation	Degrees of Freedom	Mean Squares	F
V (Ventilation rate)	2	1287.40	118.92**
O (Outlet height)	1	48.32	4.46*
H (Heat condition)	1	2311.40	213.52**
VO	2	8.78	<1
VH	2	754.39	69.68**
OH	1	0.18	<1
VOH	2	16.16	1.49
R (Replicates)	2	42.27	3.90*
ERROR (1)	22	10.82	
D (Distance from inlet)	10	94.44	119.27**
J (Height from inlet)	4	73.90	93.33**
DJ	40	33.51	42.32**
DV	20	6.22	7.86**
JV	8	2.65	3.34**
DJV	80	3.47	4.38**
DO	10	1.11	1.41
JO	4	0.90	1.14
DJO	40	0.52	<1
DVO	20	0.55	<1
JVO	8	0.82	1.02
DH	10	86.36	109.07
JH	4	61.88	78.15**
DJH	40	33.18	41.91**
DVH	20	4.99	6.30**
JVH	8	4.28	5.41**
DOH	10	0.66	<1
JOH	4	0.38	<1
ERROR (2)	1604	.79	

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

5.4 Multiple Regression

The analyses of variance in tables 4 and 10 show that there is a relationship between the gas concentrations and ventilation rate, heat condition, outlet height, distance from inlet, and height from floor. In addition, a number of the interactions also contribute toward the variation in gas concentrations. In view of this, the general model considered for the multiple regression, which included all the main effects plus some of the significant second order interactions, was as follows:-

$$Y = A_0 + A_1V + A_2V^2 + A_3D + A_4J + A_5O + A_6H + A_7VH + A_8OH + A_9DJ$$

where Y = dependent variable (concentration of NH_3 or CO_2),

V = ventilation rate (cubic feet per minute),

D = distance from inlet (inches),

J = height from floor (feet),

O = outlet height (inches),

H = heat condition (no units),

A_0 = intercept,

and $A_1 \ldots A_9$ = multiple partial regression coefficients.

While it was desirable to keep the regression equation as simple as possible, it was necessary to include all the important variables to determine their effect and to ensure a good relationship between the dependent and the independent variables. Thus, a computer programme (17) for a stepwise multiple regression was used to determine the relationship.

5.4.1 Regression Analyses for Ammonia

The results of the regression analysis for NH_3 indicated that ventilation rate was of prime importance in determining the gas

concentration. Ventilation rate and ventilation rate squared together accounted for 72.4% of the variation (table 14). The other main effects and interactions were found to contribute only 10% to the variation The inclusion of these variables reduced the standard error of the estimate by less than 2 ppm from 13 ppm. From a statistical viewpoint, most of these variables made a significant contribution towards reduction of the sum of squares. However, the practical significance of including these variables in the equation is negligible and hence only ventilation rate and ventilation rate squared have been included in the final equation.

TABLE 14: REGRESSION ANALYSIS RESULTS FOR AMMONIA.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Attributable to Regression	2	888493.37	444246.68	2889.32**
Deviation from Regression	1977	339190.62	171.56	
Total	1979	1237392		

Regression Equation

$$Y = 143.503 + 0.00048V^2 - 0.48035V$$

Multiple Correlation Coefficient = 0.851

Cumulative Proportion of Sum of Squares Reduced = 0.724

Standard Error of the Estimate = 13.09 ppm.

** Significant at the .01 level of probability.

5.4.2 Regression Analysis for Carbon Dioxide

The results of the regression equation for CO_2 are given in table 15. As in the case of NH_3, ventilation rate was of prime importance in determining the gas concentration. In this case, ventilation rate and ventilation rate squared accounted for 73.4% of the variation. The remainder of the variables accounted for approximately 10%. Their inclusion, while reducing the standard error of the estimate from 245 ppm to 180 ppm, is not considered to be of any practical advantage. The regression equation described in table 15 therefore includes only ventilation rate and ventilation rate squared as the independent variables.

TABLE 15: REGRESSION ANALYSIS RESULTS FOR CARBON DIOXIDE.

Source of Variation	Degress of Freedom	Sum of Squares	Mean Square	F
Attributable to regression	2	327026688	163513344	2720**
Deviation from regression	1977	118813952	60098	
Total	1979	445840640		

Regression Equation

$$Y = 2907 + 0.01125V^2 - 10.62V$$

Multiple Correlation Coefficient = 0.856

Cumulative Proportion Of Sum of Squares Reduced = 0.734

Standard Error of the Estimate = 245 ppm

** Significant at the .01 probability level.

The above two equations display the importance of ventilation rate in determining the concentration of gases in the atmosphere. This result is as expected. To determine the effects of the other four independent variables, the data were broken down into individual ventilation rates. Multiple regression analyses were again carried out. All of the same variables were used, except ventilation rate which was held constant.

The proportions of the sums of squares reduced for both gases at the three ventilation rates varied from 9% to 35%. The amount of variation accounted for using these independent variables did not follow a consistent pattern over the three ventilation rates for both gases. The regression equations from these analyses, therefore, were not considered important and are not presented here.

5.5 Relationship Between Temperature and Gas Concentration

From the analyses of variance of the two gas concentrations, it was shown that heat condition had a significant effect both on mean concentrations and on the distribution of the gases. The non-isothermal heat condition was an attempt to simulate the conditions that would occur in practice. This heat condition resulted in higher mean concentrations for the two gases and different distribution patterns than with the isothermal heat condition. Therefore, it seemed appropriate to study the relationship between temperature and the gas concentrations at the non-isothermal heat conditions.

Figures 32 - 43 inclusive were plotted to show the relationship between temperature and the mean gas concentrations at different levels of D and J for each of the three ventilation rates. The temperature and gas concentration data plotted here are means for the non-isothermal heat conditions over both levels of outlet height. It is clear from these

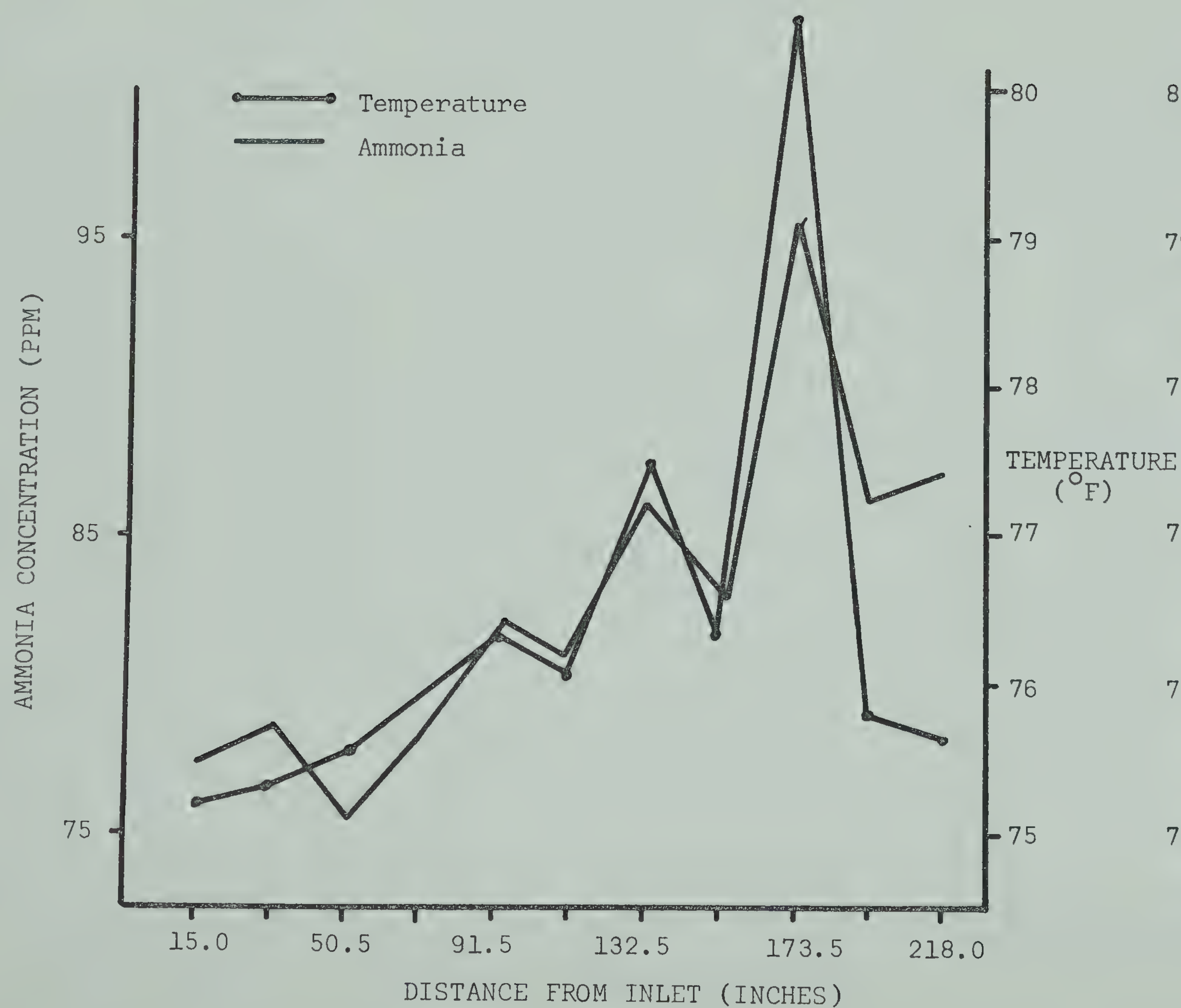

Figure 32. Graph illustrating the relationship between ammonia concentration and temperature at the different distances from inlet (165 cfm).

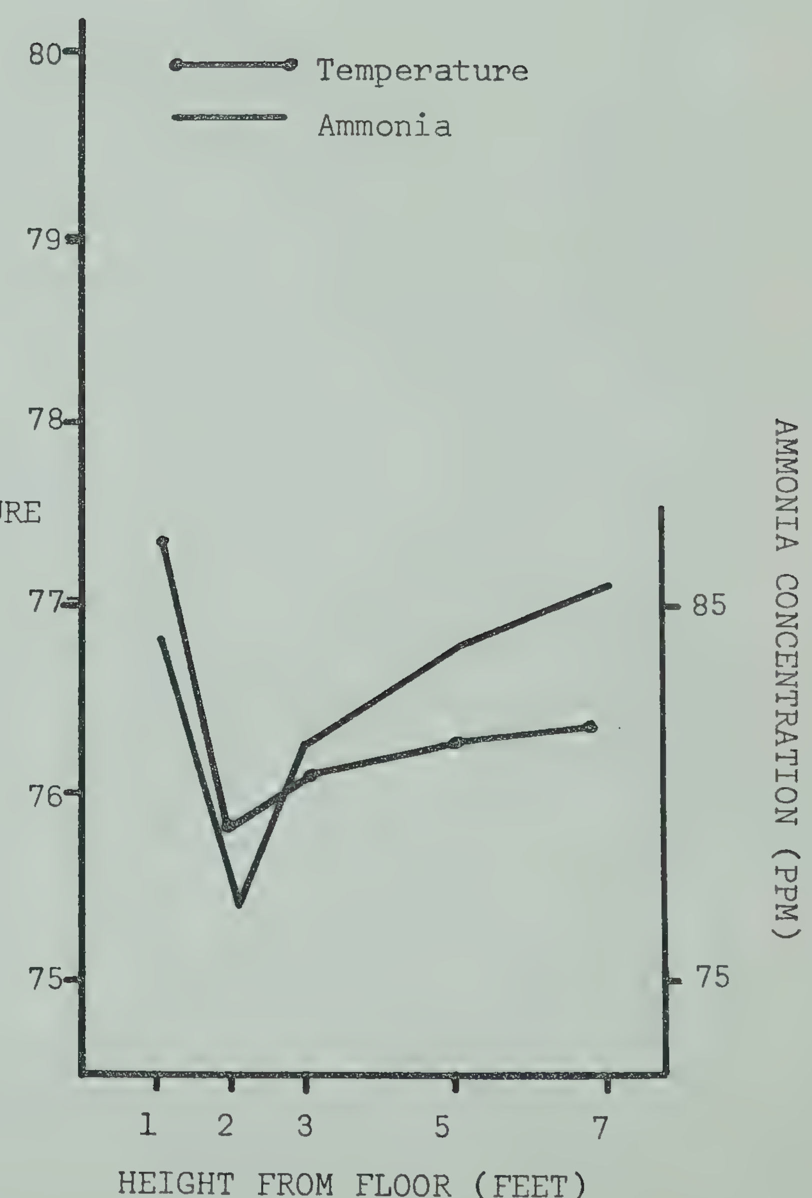

Figure 33. Ammonia concentration and temperature relationship at the different heights from floor (165 cfm).

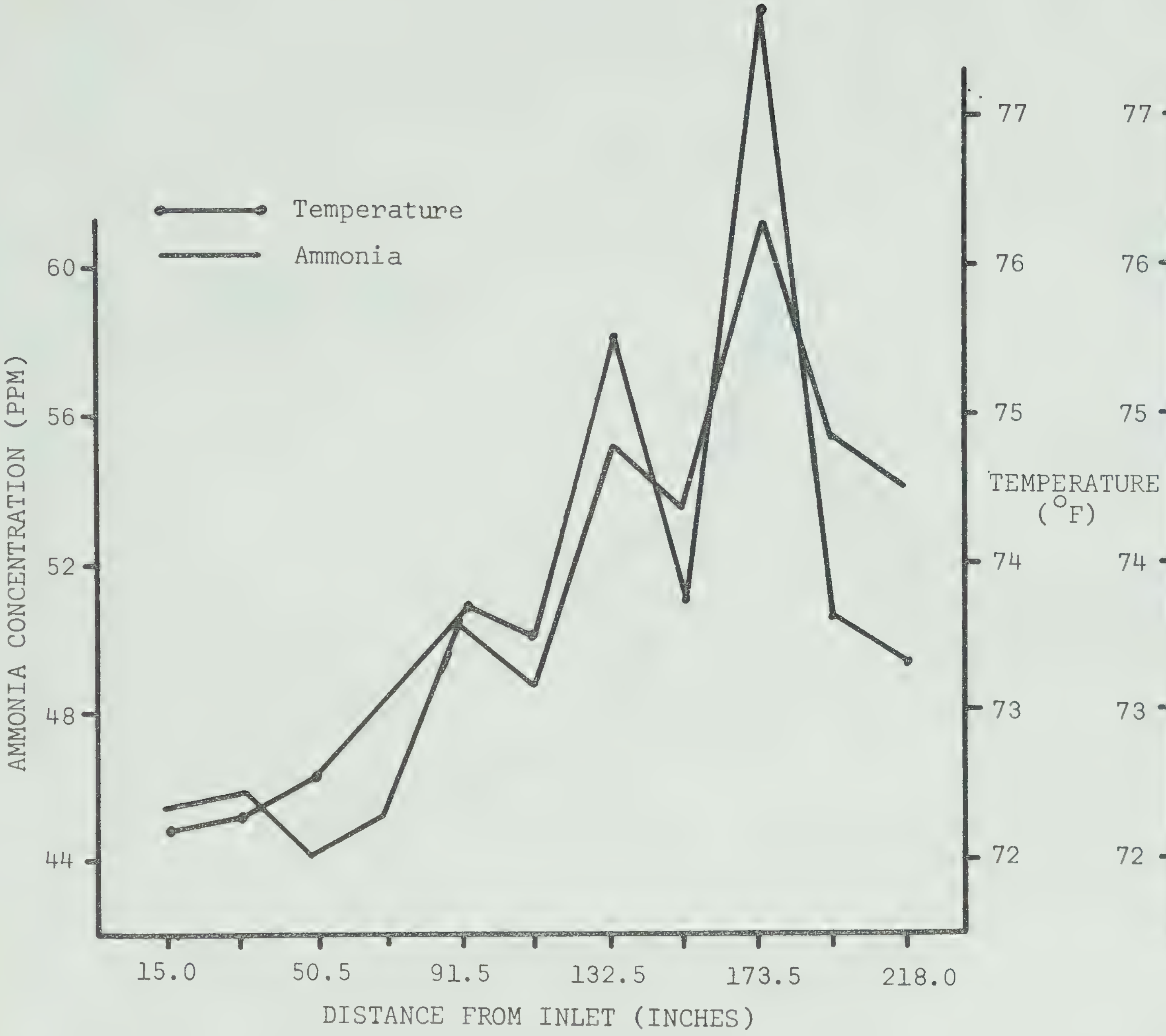

Figure 34. Graph illustrating the relationship between ammonia concentration and temperature at the different distances from inlet (261cfm).

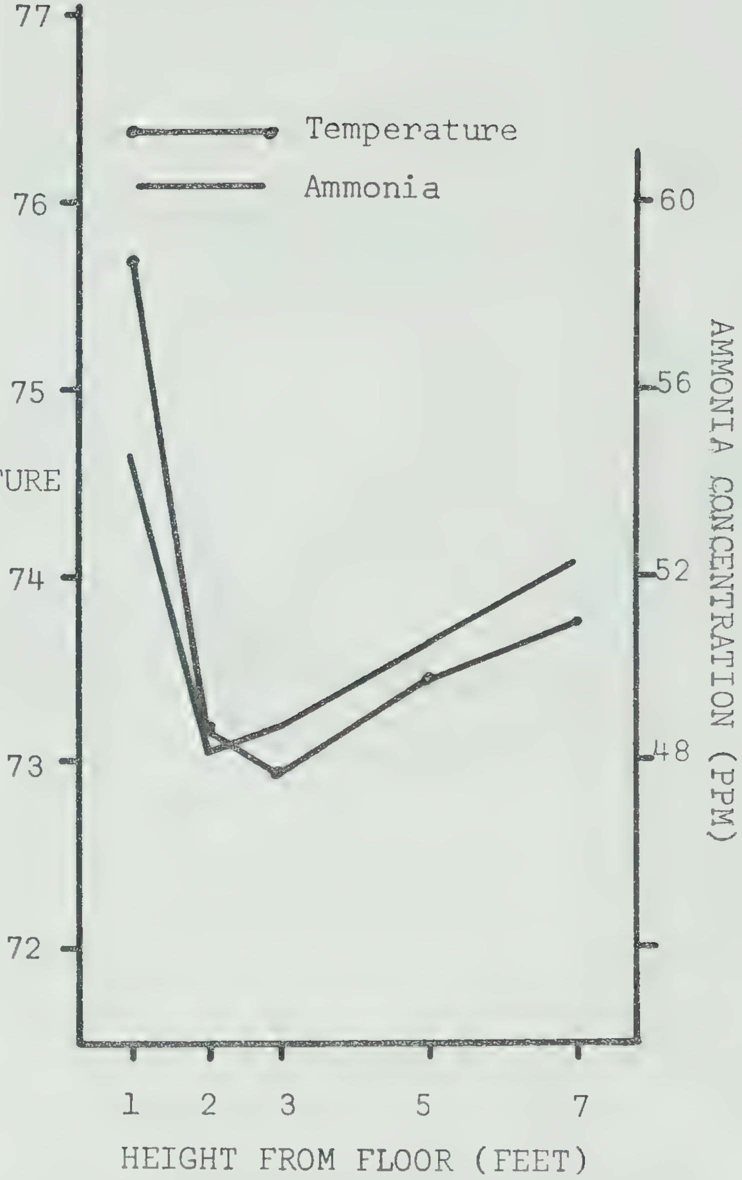

Figure 35. Ammonia concentration and temperature relationship at the different heights from floor. (261 cfm).

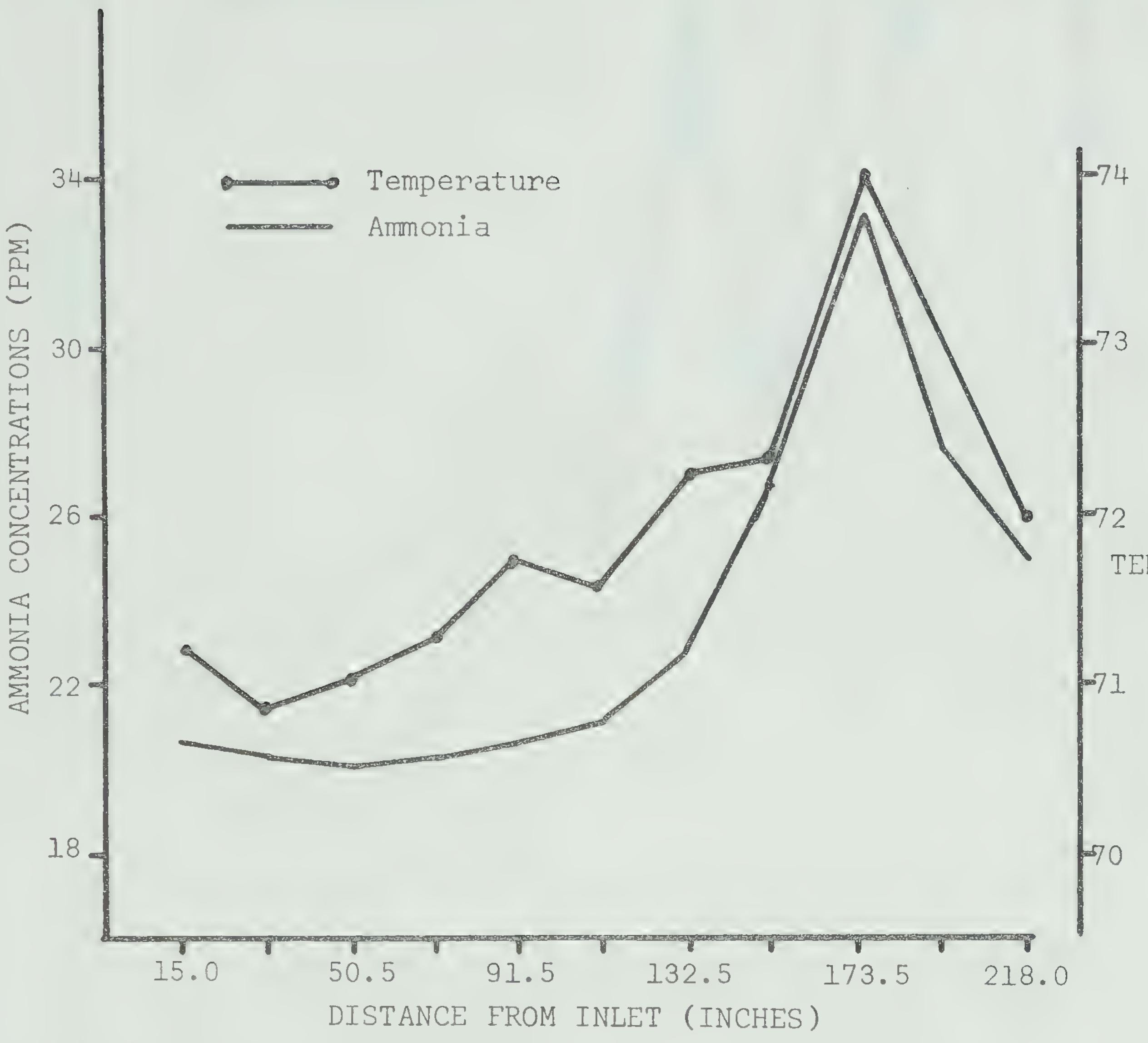

Figure 36. Graph illustrating the relationship between ammonia concentration and temperature at the different distances from inlet (549 cfm).

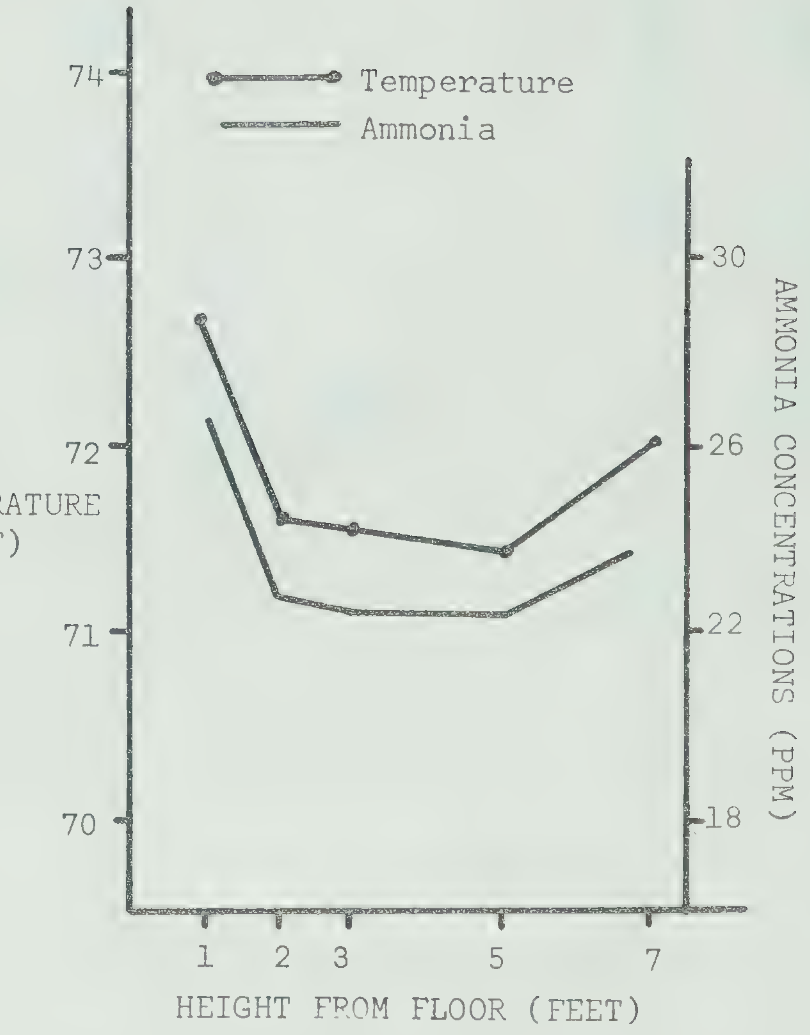

Figure 37. Ammonia concentration and temperature relationship at the different heights from floor (549 cfm).

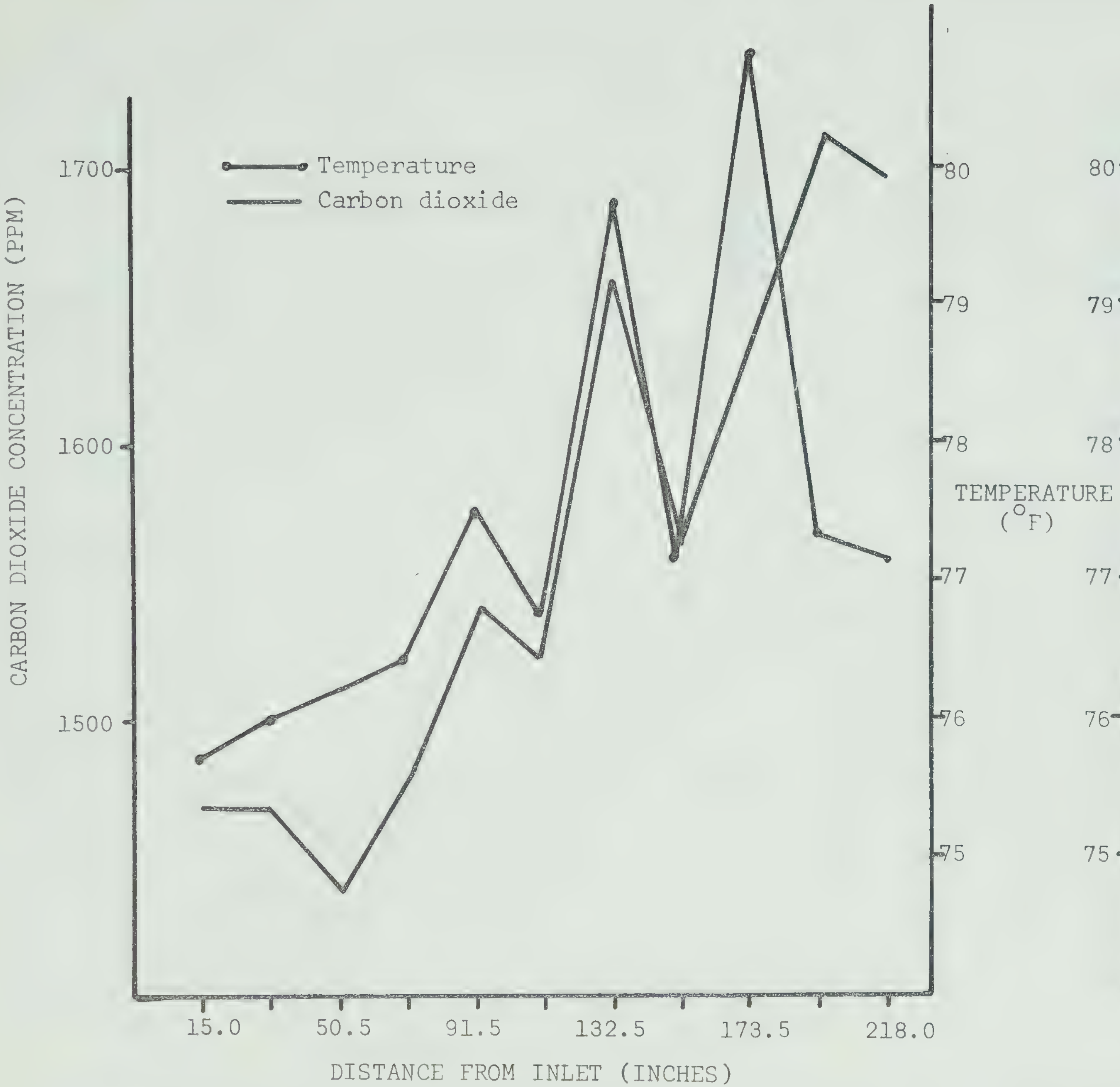

Figure 38. Graph illustrating the relationship between carbon dioxide concentration and temperature at the different distances from inlet (165 cfm).

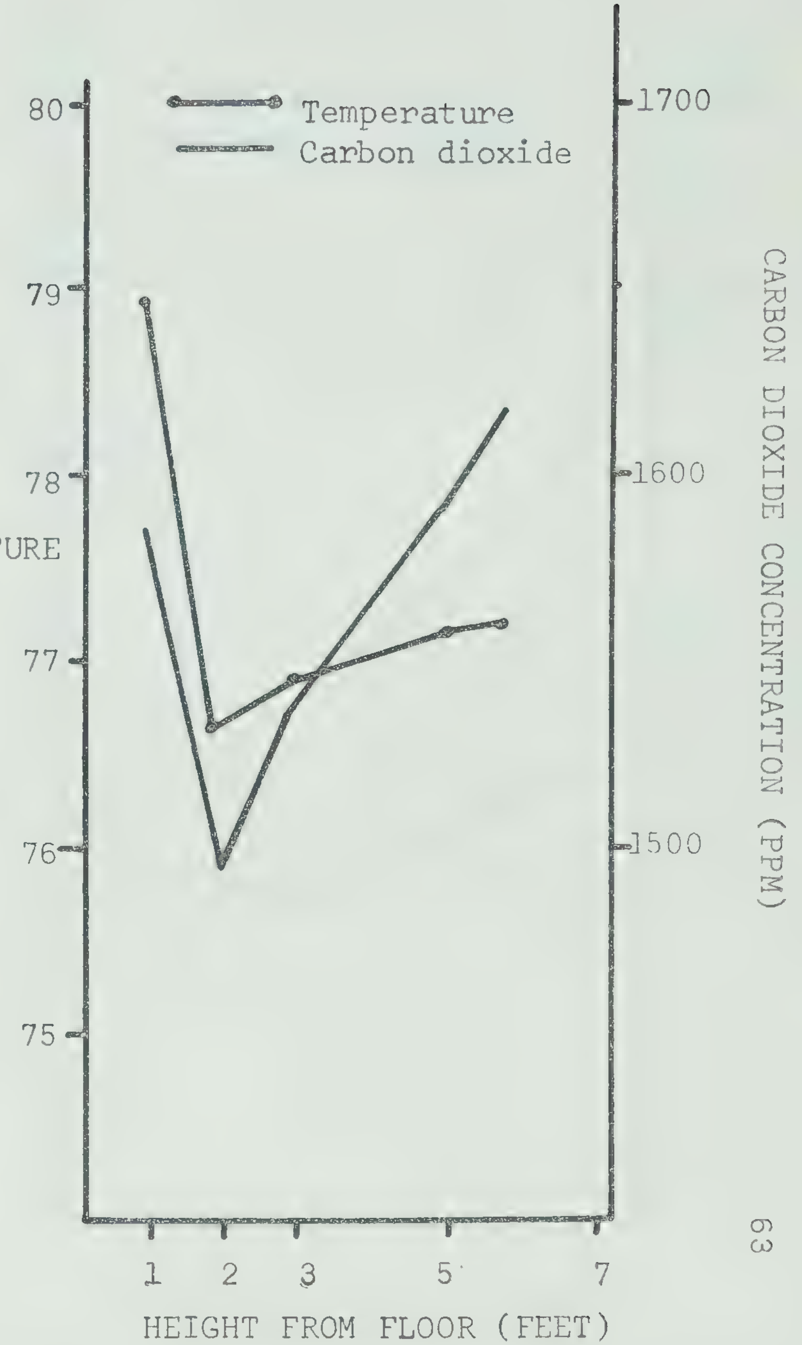

Figure 39. Carbon dioxide concentration and temperature relationship at the different heights from floor (165 cfm).

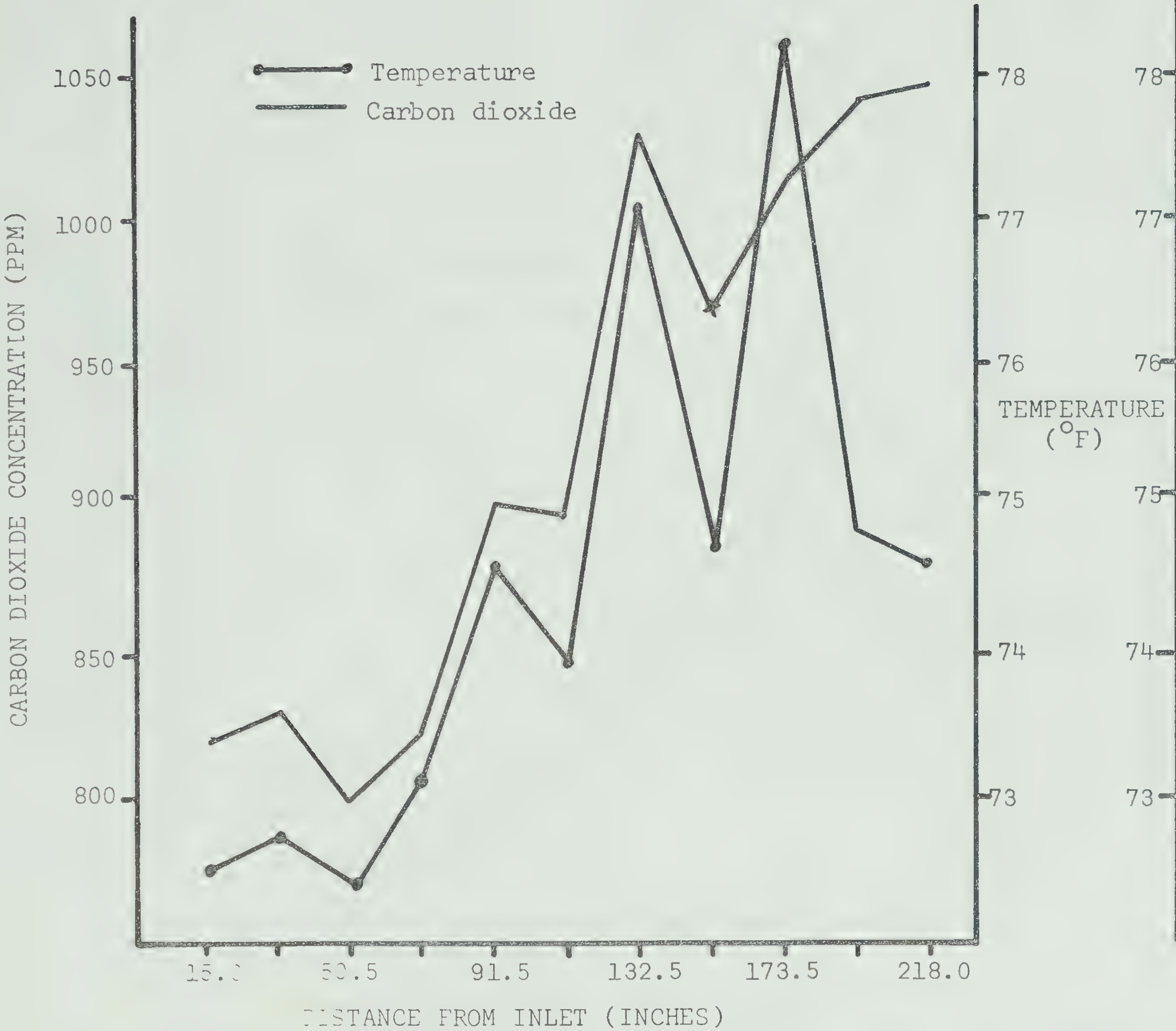

Figure 40. Graph illustrating the relationship between carbon dioxide concentration and temperature at the different distances from inlet (261 cfm)

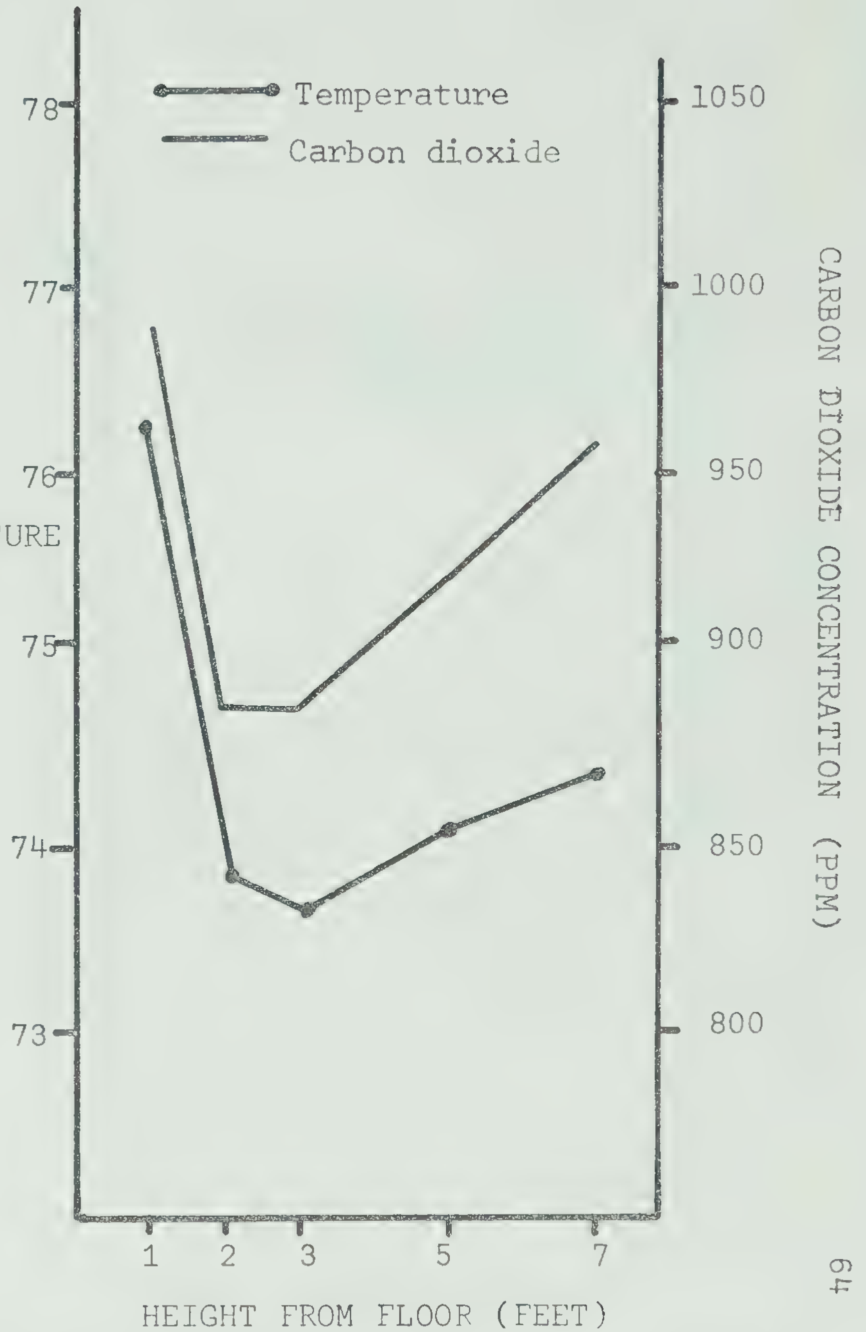

Figure 41. Carbon dioxide concentration and temperature relationship at the different heights from floor (261 cfm).

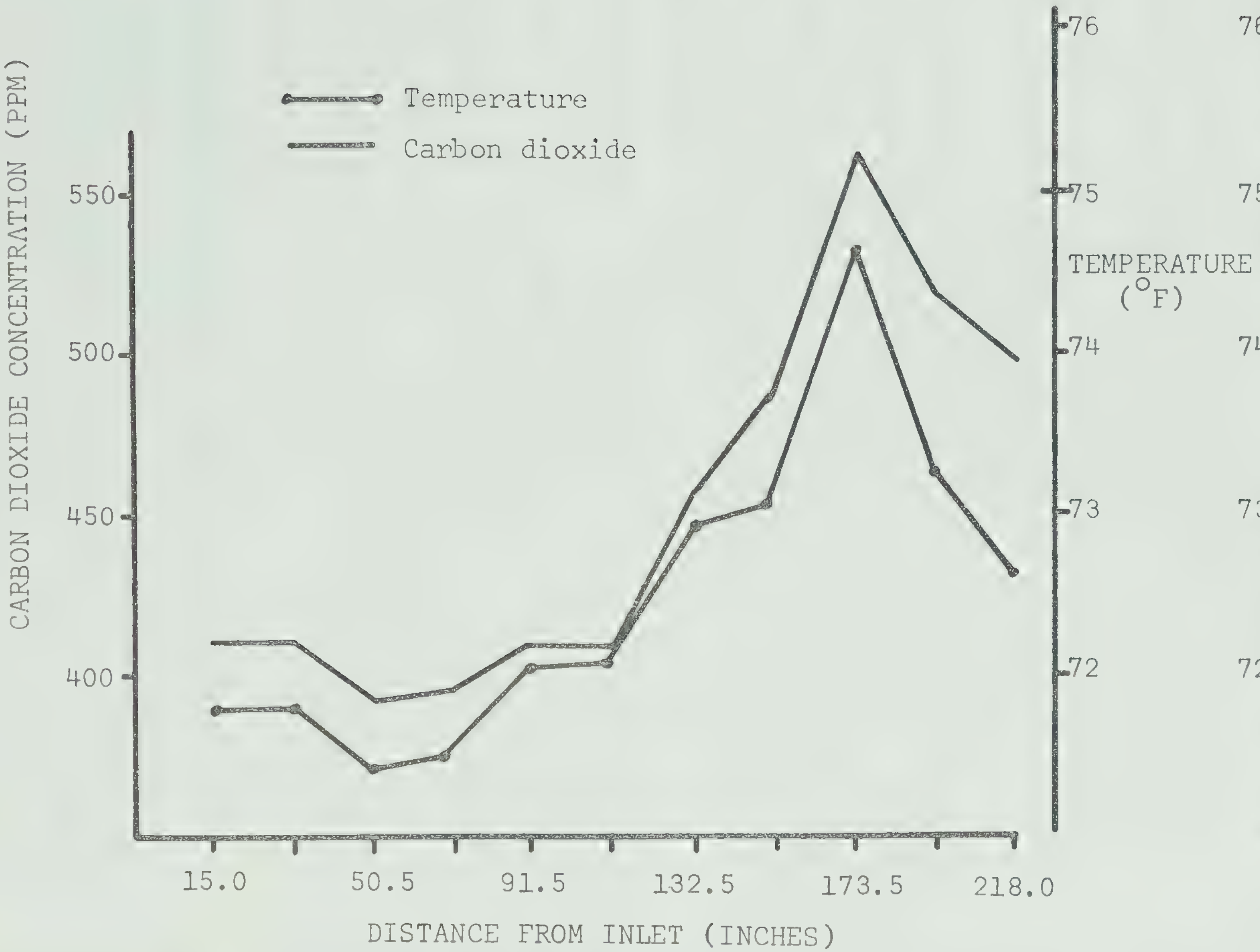

Figure 42. Graph illustrating the relationship between carbon dioxide concentration and temperature at the different distances from inlet (549 cfm).

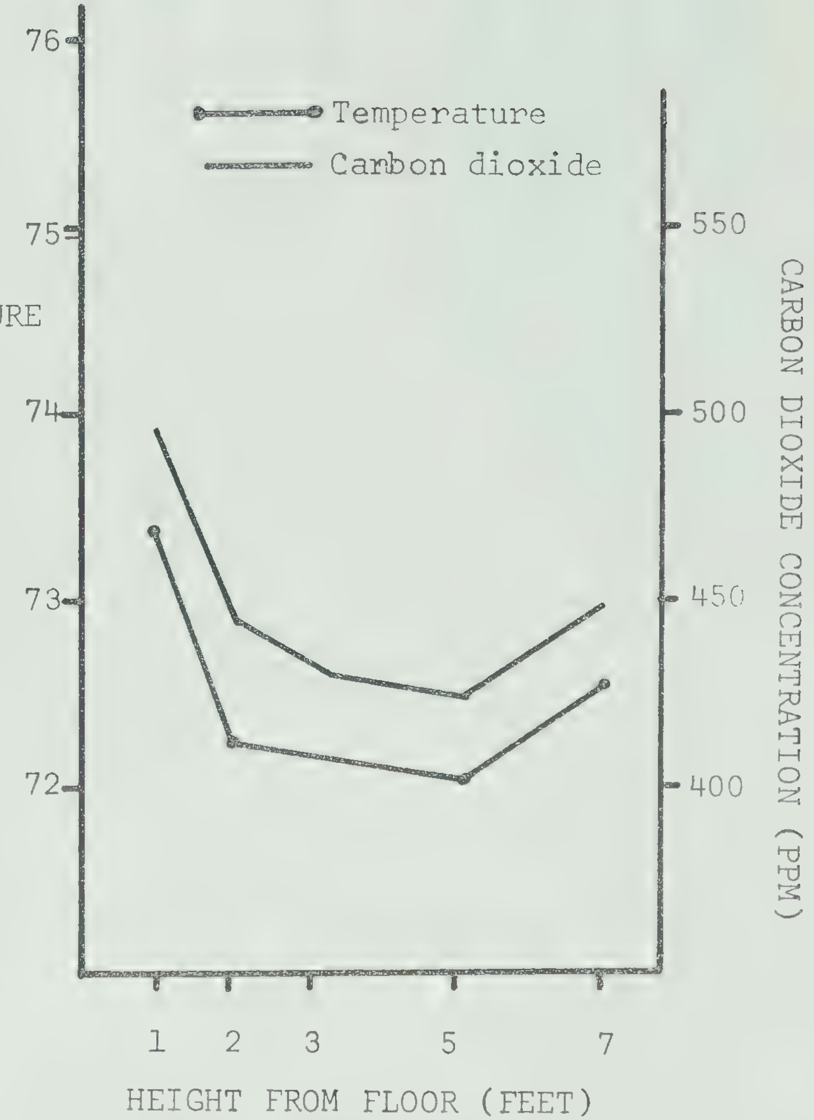

Figure 43. Carbon dioxide concentration and temperature relationship at the different heights from floor (549 cfm)

graphs that the general trend for gas and temperature is similar. An interesting point to note is that in figures 38 and 39 (mean concentrations of both gases at different levels of height from floor at 165 cfm) the gas concentration is slightly higher at the 7 foot level than at the 1 foot level.

The general trend of an increasing gas concentration with increasing distance from the inlet has already been mentioned. Figures 30,32,34,36 38,40 and 42 show the temperature and gas concentrations plotted against distance from inlet (D) for both gases at the three ventilation rates. In the case of NH_3, the effect of three of the gas diffusion units at 91.5, 132.5 and 173.5 inches from the inlet end of the chamber can be seen as peaks on the graph at ventilation rates of 165 and 261 cfm (figures 32 and 34) while at a ventilation rate of 549 cfm (figure 36) only the effect of the gas diffusion unit nearest the outlet is obvious. The effect of the gas diffusion unit at 50.5 inches from the inlet is not obvious at any of the three ventilation rates. The peaking of gas concentrations and temperature at 173.5 inches from the inlet must be related to the air-flow characteristics of the chamber.

In the case of CO_2, a similar trend occurs for the temperature as with NH_3. This is to be expected as all conditions were similar for both experiments except for the gases being used. The trend for gas concentration, however, is slightly different. At ventilation rates of 165 and 261 cfm (figures 38 and 40) the highest gas concentrations were found nearer to the outlet than with NH_3.

5.5.1 Temperature-Gas Concentration Regression Analyses

Figures 30 - 41 have shown that both temperature and gas concentration varied in a similar way. To determine the degree of

relationship between these two variables and to obtain a prediction equation for gas concentration from temperature, regression analyses were carried out for both gases at the three ventilation rates. The dependent variables for these analyses were concentrations of NH_3 and concentrations of CO_2. The general form of the equations are

$$Y = A_0 + A_1T^3 + A_2T^2 + A_3T$$

where Y = dependent variables (concentration of NH_3 or CO_2)

T = temperature (^oF)

A_0 = constant

A_1, A_2, A_3 = multiple partial correlation coefficients.

Details of the regression analyses are present in tables 16 - 21 inclusive.

TABLE 16: TEMPERATURE-GAS CONCENTRATION REGRESSION ANALYSIS RESULTS FOR AMMONIA AT A VENTILATION RATE OF 165 CFM.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to regression	1	12327.19	12327.19	336.49**
Deviation from regression	218	7986.32	36.63	
Total	219	20313.51		

Regression Equation:

$Y = -115.38 + 2.58T$

Multiple correlation coefficient = 0.779

Cumulative proportion of sum of squares reduced = .607

Standard Error of Estimate = 6.05 ppm

** Significant at .01 level of probability.

TABLE 17: TEMPERATURE-GAS CONCENTRATION REGRESSION ANALYSIS RESULTS FOR AMMONIA AT A VENTILATION RATE OF 261 CFM.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to regression	2	9849.91	4924.95	159.09**
Deviation from regression	217	6717.65	30.95	
Total	219	16567.56		

Regression Equation:

$$Y = -707.71 + 17.15T - 0.0932T^2$$

Multiple correlation coefficient = 0.771

Cumulative proportion of sum of squares reduced = 0.595

Standard Error of Estimate = 5.56 ppm.

** Significant at .01 level of probability.

TABLE 18: TEMPERATURE-GAS CONCENTRATION REGRESSION ANALYSIS RESULTS FOR AMMONIA AT A VENTILATION RATE OF 549 CFM.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to regression	2	6252.19	3126.09	31.60**
Deviation from regression	217	2146.44	9.89	
Total	219	8398.63		

Regression Equation:

$$Y = 142.42 + 0.06558T^2 - 6.37T$$

Multiple correlation coefficient = 0.863

Cumulative proportion of sum of squares reduced = 0.744

Standard Error of Estimate = 3.14 ppm.

** Significant at .01 level of probability.

TABLE 19: TEMPERATURE-GAS CONCENTRATION REGRESSION ANALYSIS RESULTS FOR CARBON DIOXIDE AT A VENTILATION RATE OF 165 CFM.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to regression	2	4910397	2455198	221.1**
Deviation from regression	327	3631069	11104	
Total	329	8541466		

Regression Equation:

$$Y = -17760 + 337.62T - 0.01461T^3$$

Multiple Correlation Coefficient = 0.758

Cumulative proportion of sum of squares reduced = 0.575

Standard Error of Estimate = 105.53 ppm.
** Signficicant at .01 level of probability.

TABLE 20: TEMPERATURE-GAS CONCENTRATION REGRESSION ANALYSIS RESULTS FOR CARBON DIOXIDE AT A VENTILATION RATE OF 261 CFM.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to regression	2	3980850	1990425	201.84**
Deviation from regression	327	3224643	9861	
Total	329	72205493		

Regression Equation:

$$Y_C = -12324.47 + 307.53T - 1.73T^2$$

Multiple correlation coefficient = 0.743

Cumulative proportion of sum of squares reduced = 0.552

Standard Error of Estimate = 99.3 ppm.

** Significant at .01 level of probability.

TABLE 21: TEMPERATURE-GAS CONCENTRATION REGRESSION ANALYSIS RESULTS FOR CARBON DIOXIDE AT A VENTILATION RATE OF 549 CFM.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Attributable to regression	2	1334327	667163	199.6**
Deviation from regression	327	1092622	3341	
Total	329	2426949		

Regression Equation:

$$Y = -6444 + 148.27T - 07327T^2$$

Multiple correlation coefficient = 0.741

Cumulative proportion of sum of squares reduced = 0.550

Standard Error of Estimate = 57.8 ppm.

** Significant at .01 level of probability.

6. DISCUSSION

Although the studies of CO_2 and NH_3 distributions were carried out separately, the results are similar and therefore will be discussed together.

In this experiment, an attempt was made to simulate conditions existing in one pen of a piggery. The dimensions of the chamber were chosen to meet this objective and the ventilation rates used were of the same order as found in practice. The simulation of gas and heat production resulted in conditions which were considered to be within the range encountered under practical conditions. However, there were a number of factors which may deviate from practice. Apart from the gas diffusion units, no obstacles existed to the flow of air. Thus, there were unlikely to be areas of sluggish air movement which might result in accumulations of gases. Even though the lowest ventilation rate (165 cfm) approached that used under winter conditions, when considered on the basis of air change per hour (7.8), it might be considered high. This higher air change per hour rate may cause more turbulence within the chamber and thus diffuse the gases more effectively from their points of generation. Simulation of sensible heat production was carried out using standard data for pigs of this weight (2). However, these units,which were coated with flat black paint,may not have had the same ratio between the modes of heat transfer as that of the live animals. Nevertheless,temperatures measured in the chamber were considered representative of those found in practice.

6.1 Mean Concentrations

The methods postulated for removing heavy and light gases from the atmosphere have been discussed in the review of literature. The use of high or low outlet heights did not significantly effect the mean

concentration of either CO_2 or NH_3 under the non-isothermal heat condition. Under the isothermal heat condition, the low level outlet height resulted in an overall lower mean concentration of both CO_2 and NH_3. The higher outlet height did not reduce the concentration of NH_3 under either heat condition. These results would seem to suggest that, under isothermal conditions, reduction in concentration of a noxious gas may best be achieved by placing the air outlets close to the site of production. However, these conditions rarely occur in practice.

An example, where isothermal conditions might occur, would be the air space between the surface of slurry and a slatted floor. Siting of extraction points beneath slatted floors has been used for some time. The results of this experiment suggest that there may be some merit in the practice. However, on a commercial scale, it would be necessary to have the extraction points evenly distributed around the perimeter of the building to achieve any practical benefit.

The effect of height of outlet under non-isothermal conditions was negligible.

For both gases, a significantly lower concentration was found with the isothermal heat condition. However, a study of the outlet height x heat condition interactions (figures 16 and 26) indicated that the lower concentrations of both gases under isothermal conditions is accounted for by the low level outlet height. It would seem possible that the air movement pattern under <u>isothermal conditions</u> and <u>low outlet height</u> are such as to cause a proportion of the gases to move directly to the outlet at levels lower than 1 foot. This would **imply** a slightly higher concentration at levels below the lowest sampling height of one foot, thus accounting for the lower mean concentration recorded for the 55 sampling points.

The mean concentrations of both gases over the three ventilation rates displayed a very similar trend (figures 12 and 22). This effect of ventilation rate on the mean concentrations was due to the dilution effect of the increased quantities of air.

In general, there was an increasing concentration of both gases with increasing distance from the inlet (figures 13 and 23). In both instances, the peak concentration occured in the vicinity of the gas diffusion unit nearest the outlet. A study of the data in Appendices III and IV reveals that this high concentration was due to high levels recorded at the one foot level over this gas diffusion unit. This high concentration may be due to an upward air movement at this point. Nonetheless, there was a gradual increase in the concentration of the gas from inlet to outlet. A number of ventilation systems currently in use in North America incorporate a nest of fans situated at one station. Air flows from inlets situated around the perimeter of the house to the fans. This air will gradually pick up contaminants of all forms and may adversely effect the health and/or performance of the stock adjacent to the fans.

The effect of height from floor was found to be significant for both gases. The overall means for both heat conditions indicated that the highest concentrations occurred at the one foot level and the lowest concentrations at the 5 foot level (figures 14 and 24). However, observation of the gas concentration curves in figures 31 and 37 indicates that under non-isothermal heat condition and low ventilation rate the highest gas concentrations occurred at the 7 foot level. Noren et al (27) found that in some cases the CO_2 concentration near the ceiling was twice that near the floor. They surmised that expired CO_2 is at a higher temperature than the ambient air and will thus tend to accumulate near ceiling level. Concentration differences

between floor and ceiling were not as great as that found by Noren. However, there does seem to be a tendency for warmer gases to accumulate near the ceiling. This phenomenon might be important in a situation where poultry are housed in battery cages. It is possible that, under winter ventilation conditions, the birds in the top row of cages may be subjected to stress due to high concentrations of expired CO_2. All the graphs illustrating the effect of height from floor show a similar trend. A constant gradient of concentration from source (1 foot) to ceiling was not found in either experiment. Thus, the theoretical Fickian diffusion does not hold.

6.2 Mean Temperatures

The effect of the independent variables on the mean temperatures followed the expected course. Both heat condition (H) and ventilation rate (V) had the most significant effect on temperature. Under non-isothermal conditions differences in temperature existed at different levels of height from floor (J) and distance from inlet (D). Significant difference existed between the replicates. This may be due to any of a multiplicity of factors, although it is considered that the most likely cause was a result of changes in the ambient temperature of the laboratory in which the chamber was located.

6.3 Multiple Regression Analyses

The multiple regression analyses indicated that only ventilation rate of the independent variables was of practical importance in determining the concentration of either of the gases. The other independent variables, while contributing significantly from a statistcial viewpoint, did not have any practical relevance and were not included in the equation. When regression analyses were carried out holding ventilation rates constant,

the other independent variables contributed very little. This would seem to suggest that some variable(s) not used in this experiment was effecting the pattern of gas concentrations. One variable not included in the experiment which might have been important is turbulence.

The effect of turbulence on diffusivity was studied by Taylor (32) when carrying out meteorological research in the early years of this century. These theories on diffusivity were utilised by Heldman (19) to study the effect of turbulence on the dispersion of an aerosol in a food packaging area. A similar approach in this investigation might have revealed the reasons for concentration variations. However, the primary purpose of this project was to study the variations in gas concentrations that might exist under different ventilation conditions.

6.4 Temperature-Gas Concentration Relationship

In the chamber used for these experiments, both heat and gas production occured at roughly the same site. Transfer of heat in a still atmosphere by the process of heat conduction involves the transfer of energy by molecular movement. The diffusion of gases in a still atmosphere follows a similar pattern. This movement of a gas through the atmosphere is caused by a concentration gradient and is explained by Fick's Law. This however, is a much slower process than convective or eddy diffusion. Convective diffusion involves macroscopic or particle mixing compared to microscopic molecular mixing by Fickian diffusion (3). Any diffusible component of the atmosphere such as heat can be similarly transported by eddy diffusion.

In these experiments, the temperature and gas concentrations followed the same general trend for the three ventilation rates. It would seem, therefore, that both the noxious gases and heat diffused in a similar

manner. The regression analyses shown in table 15 - 21 show the degree of relationship between these two variables. Thus, temperature may be used to predict the gas concentration at any point with a fair degree of accuracy. All the correlation coefficients are significant at the .01 level of probability.

7. CONCLUSIONS

Under the conditions of the experiments described, the following conclusions are made:

1. No practical difference was found in the distribution pattern of the two gases, carbon dioxide and ammonia, thus discounting the theory that gases tend to accumulate in the atmosphere at different levels depending on their relative densities.
2. Fick's Law of gaseous diffusion is not applicable in this situation over the range of ventilation rates used.
3. The variables causing significant differences in the concentration of ammonia were ventilation rate, outlet height, distance from inlet, and height from floor.
4. The variables causing significant differences in concentration of carbon dioxide were ventilation rate, outlet height, heat condition, distance from inlet and height from floor.
5. In both experiments, the outlet height by heat condition interaction was significant. It was found that low outlet height reduced the concentration of ammonia and carbon dioxide under the isothermal heat condition. Under non-isothermal heat conditions the effect of outlet height was negligible.
6. Multiple regression analyses indicated that, of the independent variables, only ventilation rate was of practical importance in determining the concentrations of carbon dioxide and ammonia.
7. For both gases, the correlation coefficients between temperature and gas concentration at the three ventilation rates were highly significant. Regression equations for the prediction of gas concentration using temperature as the independent variable were presented.

8. BIBLIOGRAPHY

1. Alberta Department of The Attorney General. 1968. Inquisition No. Inq./7176, Cor./A - 62. Edmonton, Alberta.

2. American Society of Agricultural Engineers. 1969. Agricultural Engineers Yearbook. A.S.A.E., St. Joseph, Michigan.

3. American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1967. Handbook of Fundamentals. A.S.H.R.A.E., New York. p. 65 - 78.

4. Anderson, D.P., C.W. Beard and R.P. Hanson. 1964. The adverse effects of ammonia on chickens including resistance to infection with Newcastle disease virus. Avian Diseases, 8: 369-379.

5. Baxter, S.H. 1969. The environmental complex in livestock housing. Farm Building Report No. 4. The Scottish Farm Building's Investigation Unit, Aberdeen.

6. Beckman Instruments ,Inc. 1968. Models 215A, 315A and 415A infrared analyzers. Beckman instructions 1635-B. Beckman Instruments Inc., Process Instruments Division, Fullerton, California.

7. Berglund, S., G. Aniansson and I. Ekesbo. 1965. Liquid manure handling. Swedish Institute of Agricultural Engineering, Bulletin No. 310. Upsala, Sweden.

8. Blaxter, K.L. 1962. The Energy Metabolism of Ruminants. Hutchinson Scientific and Technical, London.

9. Boothroyd, A. 1966. Carbon dioxide poisoning in pigs. Vet. Rec. 78: 770.

10. Canada Department of Agriculture. 1967. Proceedings, Work Planning Meeting, Dairy and Beef Cattle Research. Ottawa. p. 143.

11. Charles, D.R. and C.G. Payne. 1966. The influence of graded levels of atmospheric ammonia on chickens. Brit. Poult. Science, 7: 177 - 187.

12. Clark, J.W. and W. Viessman Jr. 1965. Water Supply and Pollution Control. International Textbook Co., Scranton, Pennsylvania.

13. Comberg, G. and M.F. Wolfermann. 1966. Further investigation into the problem of harmful gases in the atmosphere of slatted floor piggeries. Bauen a.d. Lande. 17: 46 - 49.

14. Dukes, H.H. 1955. The Physiology of Domestic Animals. Comstock Publishing Associates, Ithaca, New York.

15. Easton, M. 1968. Analysis of variance library programme, C.S.017. Department of Computing Science, University of Alberta, Edmonton.

16. Goff, J.A. 1949. Standardisation of thermodynamic properties of moist air. A.S.H.V.E. Transactions, 55: 463.

17. Grobben, G. 1970. Stepwise multiple regression library programme, C.S. 101. Department of Computing Science, University of Alberta, Edmonton.

18. Hammer, W. 1964. Manure storage and disposal in piggeries with slatted floors. Proceedings of C.I.G.R., Lausanne, 2: 563 - 571.

19. Heldman, D.R. 1968. Relationship between aerosol dispersion and air turbulence in a food packaging area. Paper no. 68-372 presented at the A.S.A.E. Annual Meeting, Logan, Utah.

20. Hilliger, H.G. 1966. Formation of gases in poultry houses from deep litter and dropping pits. Arch. Geflügelk. , 30: 69 - 86.

21. Hogsved, O. and P. Holtenius. 1968. Liquid manure gas poisoning. Paper presented at World Veterinary Conference, Opatija, Yugoslavia.

22. Hudek, E.P. 1967. A slotted floor confinement system for beef. Paper No. 67-403 presented at the joint CSAE/ASAE Meeting at Saskatoon, Saskatchewan.

23. Jorgensen, R. 1961. Fan Engineering. Buffalo Forge Co., Buffalo, N.Y., Chapter 9.

24. McAllister, J.S.V. Gases from dung under slats. Farm Buildings No. 11: 23 - 24, May-June, 1966.

25. McAllister, J.S.V. and J.B. McQuitty. 1965. Release of gases from slurry. Rec. Agric. Res. Min. Agric., N. Ire., 14, Part 2: 73 - 78.

26. McCabe, W.L. and J.C. Smith. 1967. Unit Operations of Chemical Engineering. McGraw-Hill Book Co., New York.

27. Noren, O., S.U. Skarp and G. Aniansson. 1967. Recent Experiences from J.T.I.'s studies on the manure gas problem. Swedish Institute of Agricultural Engineering, Upsala, Sweden. Circular No. 20.

28. Payne, C.G. 1966. Environmental temperature and the performance of light breed pullets. Proc. 13th World's Poultry Congr., Kiev, p. 480 - 485.

29. Silver, S.D. and E. Arsenal. 1946. Constant flow gassing chambers. Journal of Laboratory and Clinical Medicine. 31: 1153 - 1161.

30. Stombaugh, D.P., H.S. Teague and W.L. Roller. 1969. Effects of atmospheric ammonia on the pig. Journal of Animal Science. 28: 844 - 847.

31. Taiganides, E.P. and R.K. White. 1969. The menace of noxious gases in animal units. Transactions A.S.A.E., 12: 359 - 362, 367.

32. Taylor, G. I. 1921. Diffusion by continuous movements. Proc. London Math. Soc., Ser. 2, 20:196.

33. Turner, C.N. and H.R. Davis. 1967. A ventilating system for high density housing of poultry. Paper No. 67-942 presented at A.S.A.E. Winter Meeting, Detroit, Michigan.

34. Webster, A.J.F. 1969. Private Communication. Department of Animal Science, University of Alberta, Edmonton.

35. Wooley, J.C. 1946. Farm Buildings. McGraw-Hill Book Co. Inc., New York, p. 146 - 147.

9. APPENDICES

APPENDIX I

DETAILS OF FAN CAPACITY MEASUREMENT

Procedure used has been described (23) and was carried out as follows:

1. For each setting, 10 horizontal and 10 vertical readings of velocity pressure were taken. Average velocity pressure was calculated from

$$VP_x = \left(\frac{\sqrt{VP_{x1}} \cdot \cdot \cdot \cdot \cdot \sqrt{VP_{x20}}}{20}\right)^2$$

where VP_x = Average Velocity Pressure

Total extraction rate was then calculated from the following formula:

$$CFM_x = 1096.5\ A_x \sqrt{\frac{VP_X}{\partial_x}}$$

where CFM_x = Volume Rate (ft^3/minute)

A_x = Area of Duct at point of measurement (ft^2)

∂_x = Air Density (.074 lb/ft^3) at 70°F and 50% R.H.

Results obtained were

Cone Setting	Extraction Rate
1 3/8"	165.3 c.f.m.
1 1/2"	260.6 c.f.m.
2"	549.1 c.f.m.

APPENDIX II

LIST OF TREATMENT COMBINATIONS

Experimental Run	Ventilation Rate (CFM)	Outlet Height (O) inches	Heat Condition (H)
1	165	High	Non-isothermal
2	165	High	Isothermal
3	165	Low	Non-isothermal
4	165	Low	Isothermal
5	261	High	Non-isothermal
6	261	High	Isothermal
7	261	Low	Non-isothermal
8	261	Low	Isothermal
9	549	High	Non-isothermal
10	549	High	Isothermal
11	549	Low	Non-isothermal
12	549	Low	Isothermal

APPENDIX III

AMMONIA CONCENTRATIONS

Ammonia concentration data collected for all the combinations of the independent variables are presented in the following pages.

In the heading to each section, the Run and Replicate number are given. The Run number corresponds to the Experimental Run number in Appendix II. Concentration values are in ppm.

The columns in each section correspond to the distances from inlet and the rows to the heights from floor. Every other column is given its appropriate heading of distance from inlet (inches). Reference may be made to Figure 10 for the column headings not included. The rows in each section correspond to the heights from floor. Starting at the top row these correspond to the one foot, two feet, three feet, five feet and seven feet heights from floor.

RUN 1 REPLICATE 1

218.0 * 173.5 * 132.5 * 91.5 * 50.5 * 15.0

[illegible]	89	140	85	[illegible]	86	96	79	67	70	67
89	90	98	83	[illegible]	82	74	72	70	74	80
89	89	99	83	[illegible]	80	73	80	79	79	82
89	[illegible]	[illegible]	85	[illegible]	[illegible]	[illegible]	[illegible]	86	86	86
86	85	88	89	[illegible]	82	85	86	85	83	86

RUN 1 REPLICATE 2

218.0 * 173.5 * 132.5 * 91.5 * 50.5 * 15.0

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	88	77	69	[illegible]	66
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70	[illegible]	[illegible]	72
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	74	73	[illegible]	77	[illegible]	80
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80	83	[illegible]	75	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	[illegible]	[illegible]	[illegible]

RUN 1 REPLICATE 3

218.0 * 173.5 * 132.5 * 91.5 * 50.5 * 15.0

[illegible]	[illegible]	[illegible]	79	[illegible]	74	[illegible]	[illegible]	61	67	[illegible]
[illegible]	[illegible]	90	79	79	[illegible]	[illegible]	[illegible]	66	69	[illegible]
[illegible]	85	86	80	80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	82	79	77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	82	80	71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 2 REPLICATE 1

218.0 * 173.5 * 132.5 * 91.5 * 50.5 * 15.0

[illegible]	102	96	99	67	71	61	[illegible]	[illegible]	74	[illegible]
[illegible]	[illegible]	111	66	69	[illegible]	61	72	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	61	[illegible]	63	61	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	88	[illegible]	[illegible]	[illegible]	70	67	[illegible]	[illegible]	[illegible]

RUN 2 REPLICATE 2

218.0 * 173.5 * 132.5 * 91.5 * 50.5 * 15.0

[illegible]	[illegible]	175	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70
80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	86	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 2 REPLICATE 3

218.0 * 173.5 * 132.5 * 91.5 * 50.5 * 15.0

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	123	70	[illegible]	61	60	60	66	69	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	80	76	[illegible]	61	[illegible]	72	[illegible]	47	[illegible]
[illegible]	[illegible]	76	88	[illegible]	80	72	74	72	74	[illegible]

RUN 3 REPLICATE 1

[illegible]	*	173.5	*	[illegible]	*	91.5	*	50.5	*	[illegible]
89	86	111	85	99	85	99	82	64	76	69
92	90	96	88	99	83	76	70	72	77	[illegible]
90	89	90	88	86	77	74	79	79	82	82
93	89	89	92	83	86	86	86	86	89	89
90	93	88	86	89	88	88	86	89	89	88

RUN 3 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
90	85	140	83	99	93	99	72	69	67	67
89	89	86	86	88	83	77	70	72	76	76
89	92	90	79	85	77	74	76	76	82	82
89	86	86	83	83	85	86	89	88	86	86
89	88	89	85	88	88	86	86	88	88	85

RUN 3 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	[illegible]	111	[illegible]	90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
85	85	85	82	80	80	72	69	67	72	72
85	89	86	86	79	76	74	76	76	80	74
82	93	85	82	79	83	82	82	82	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 4 REPLICATE 1

[illegible]	*	[illegible]	*	[illegible]	*	[illegible]	*	[illegible]	*	[illegible]
90	109	175	96	67	82	60	61	64	76	82
90	108	82	99	67	61	61	64	69	76	79
85	79	79	64	67	57	61	55	63	70	76
82	82	82	76	70	64	61	70	58	55	77
67	72	85	70	72	66	73	63	69	64	69

RUN 4 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
80	93	85	82	82	67	73	54	60	44	69
67	85	67	79	58	55	57	54	58	76	72
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
58	79	64	73	72	64	67	55	55	53	64
67	63	76	82	72	64	63	67	70	66	69

RUN 4 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
82	88	67	55	61	53	50	51	58	82	67
70	74	152	82	82	57	53	51	57	70	61
79	64	55	51	54	53	51	53	50	76	67
[illegible]	67	58	54	67	61	60	57	58	44	[illegible]
61	63	61	60	61	58	54	55	58	61	61

RUN 5 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
51	51	102	58	82	53	76	47	37	39	39
[illegible]	54	51	51	67	50	42	39	39	42	44
55	55	57	58	53	44	42	42	41	47	44
58	57	58	47	53	51	50	48	51	51	50
[illegible]	[illegible]	[illegible]	[illegible]	51	[illegible]	51	51	54	53	54

RUN 5 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
51	55	54	53	82	53	76	48	38	39	39
55	54	61	54	64	51	44	39	39	41	41
57	57	53	47	54	47	42	41	42	47	48
60	57	57	51	48	47	45	44	50	50	48
57	57	57	53	53	51	51	50	51	51	51

RUN 5 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
47	53	99	53	64	48	53	48	34	35	32
45	50	55	51	45	47	42	38	37	39	38
50	51	54	50	51	41	39	41	37	44	45
53	51	50	50	42	41	44	45	47	47	47
53	53	51	45	47	47	44	42	47	47	48

RUN 6 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	117	111	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	57	[illegible]	70	[illegible]	73	111	99	[illegible]
60	57	58	61	57	58	82	70	108	105	123
57	60	61	57	57	57	61	64	66	93	96
58	55	57	51	51	57	63	64	51	47	44

RUN 6 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
64	60	82	39	47	41	38	37	39	45	47
64	58	55	70	42	41	39	39	39	42	51
[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	[illegible]	[illegible]	[illegible]	44	[illegible]
57	54	58	39	44	42	45	42	38	42	48
53	53	57	57	50	48	51	53	50	48	44

RUN 6 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
55	55	102	77	55	35	35	38	37	38	41
53	53	61	61	53	39	38	37	39	39	41
53	58	55	53	39	41	44	39	37	41	44
[illegible]	[illegible]	51	[illegible]	[illegible]	[illegible]	41	42	[illegible]	[illegible]	[illegible]
53	49	53	47	48	48	47	48	48	44	41

RUN 7 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
53	53	99	61	70	58	70	50	38	45	42
57	64	58	64	50	54	50	41	42	47	47
58	58	55	61	55	45	42	41	48	47	53
58	58	54	55	48	47	50	52	53	54	44
60	61	58	55	55	53	55	53	54	55	55

RUN 7 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
51	[illegible]	[illegible]	[illegible]	57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	51	[illegible]	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 7 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
47	53	96	55	73	51	58	50	35	35	37
53	53	51	51	54	50	42	38	38	39	42
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	53	54	54	51	48	48	46	50	48	51

RUN 8 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
64	60	131	73	44	44	38	37	38	42	45
60	67	82	64	42	39	38	37	42	[illegible]	[illegible]
53	61	61	53	42	42	42	35	38	44	47
51	53	47	41	44	42	47	47	35	34	47
[illegible]	[illegible]	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 8 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	61	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]	39
[illegible]	55	54	[illegible]	[illegible]	41	[illegible]	[illegible]	37	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45	[illegible]	[illegible]	[illegible]	41

RUN 8 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
53	55	82	79	41	37	32	35	35	38	39
53	57	70	58	37	35	37	32	38	38	38
53	47	54	50	38	39	38	34	38	38	39
50	50	53	41	38	38	42	38	31	33	35
47	47	41	41	42	42	47	39	41	39	37

RUN 9 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
23	31	47	35	28	22	18	18	18	19	19
26	29	32	29	20	19	19	18	20	20	19
23	27	28	23	20	20	22	20	26	22	19
23	26	25	25	19	19	20	22	19	16	18
27	[illegible]	[illegible]	[illegible]	[illegible]	22	[illegible]	[illegible]	23	[illegible]	[illegible]

RUN 9 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
31	32	53	38	41	22	20	20	21	21	21
27	28	29	34	21	22	22	20	21	22	23
29	31	31	29	23	22	23	20	19	23	22
26	28	28	24	23	22	24	24	22	20	23
28	29	28	26	24	25	25	25	25	26	23

RUN 9 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
22	29	70	32	29	21	18	18	19	20	20
25	28	29	22	22	19	20	19	20	22	18
[illegible]	[illegible]	[illegible]	25	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	23	24	25	23	23	23	23	22	25	22

RUN 10 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	[illegible]	[illegible]	55	[illegible]	[illegible]	[illegible]	18	[illegible]	[illegible]	22
[illegible]	[illegible]	34	[illegible]	[illegible]	[illegible]	[illegible]	19	19	21	22
[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]	[illegible]	[illegible]	19	[illegible]	21
[illegible]	[illegible]	34	[illegible]	21	[illegible]	[illegible]	[illegible]	19	19	27
25	25	25	24	25	25	22	25	23	25	21

RUN 10 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
28	29	26	41	37	41	50	47	67	67	64
27	28	28	29	32	35	32	37	44	70	57
26	29	28	29	31	32	34	37	35	50	51
25	26	25	29	28	26	28	31	37	41	53
26	26	25	25	28	25	28	26	19	20	26

RUN 10 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57
29	29	29	29	34	38	38	44	64	53	53
31	28	29	28	29	31	39	38	47	55	48
28	28	29	31	29	29	29	37	42	44	50
26	26	26	28	26	25	26	28	23	23	22

RUN 11 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
29	32	70	34	23	22	20	20	20	22	20
26	32	32	29	22	20	20	19	19	20	[illegible]
26	28	32	25	22	22	22	22	19	22	22
28	29	29	22	23	22	23	23	22	15	22
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 11 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
26	31	64	33	29	20	18	20	18	18	19
23	28	26	28	19	18	18	18	18	19	19
23	26	26	20	19	20	20	19	16	20	20
23	24	23	20	20	21	21	22	19	16	20
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 11 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
24	31	38	34	23	20	18	18	18	20	20
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	24	25	23	19	19	20	19	18	21	17
[illegible]	[illegible]	25	21	21	22	23	[illegible]	[illegible]	[illegible]	[illegible]
24	23	26	23	23	22	22	23	23	21	21

RUN 12 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
31	37	55	50	19	21	18	18	19	22	22
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	31	29	23	20	20	20	18	19	20	20
26	25	26	23	20	21	22	21	18	20	22
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 12 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
26	31	41	50	19	19	18	18	18	19	21
28	31	31	28	19	18	18	19	18	20	21
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	26	22	22	19	20	19	21	17	18	21
22	23	22	23	22	22	20	22	22	20	22

[illegible]

[illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX IV

CARBON DIOXIDE CONCENTRATIONS

Carbon dioxide concentration data collected for all the combinations of the independent variables are presented in the following pages.

In the heading to each section, the Run and Replicate number are given. The Run number corresponds to the Experimental Run number in Appendix II.

The columns in each section correspond to the distances from inlet and the rows to the heights from floor. Every other column is given its appropriate heading of distance from inlet (inches). Reference can be made to Figure 10 for the column headings not included. The rows in each section correspond to the heights from floor. Starting at the top row these correspond to the one foot, two feet, three feet, five feet and seven feet height from floor.

RUN 1 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1730	1730	1730	[illegible]	2310	[illegible]	1250	1560	1230	1310	[illegible]
1670	1640	1590	1560	1670	1500	1340	1340	1340	1370	1390
1730	1700	1670	1640	1560	1450	1340	1390	1420	1480	1560
1760	1730	1640	1590	1530	1450	1560	1560	1560	1590	1590
1670	1670	1640	1530	1560	1590	1620	1590	1560	1590	1620

RUN 1 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1670	1700	1760	1500	2170	1480	1760	1480	1170	1230	1250
1670	1670	1560	1500	1560	1500	1340	1280	1250	1370	1280
1670	1700	1670	1530	1590	1450	1340	1450	1420	1450	1480
1670	1640	1640	1560	1500	1500	1480	1500	1500	1530	1560
1640	1560	1620	1500	1560	1530	1560	1530	1560	1550	[illegible]

RUN 1 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1640	1780	1700	1480	1980	1500	1730	1500	1170	1230	1200
1640	1640	1530	1480	1480	1480	1310	1200	1230	1340	1340
1640	1700	1640	1560	1590	1440	1250	1340	1390	1450	[illegible]
1590	1670	1670	1480	1390	1420	1500	1560	1530	1530	1560
1590	1560	1560	1560	1560	1530	1560	1560	1560	1530	1530

RUN 2 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
2710	2330	2430	2500	2430	2270	[illegible]	[illegible]	1210	[illegible]	[illegible]
2040	1930	1990	1600	1600	1320	1040	[illegible]	1130	1150	[illegible]
1880	1880	1880	1600	1430	1320	1070	1150	1040	1430	1650
1770	1770	1770	1430	1430	1150	1210	1130	1130	1100	1430
1650	1260	1380	1260	1380	1430	1210	1180	1150	1320	1150

RUN 2 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
2340	2140	2260	2030	2480	2650	1060	1090	1200	1140	1480
1950	2200	1890	1810	1700	1200	1140	1030	980	1200	1530
1980	1870	1870	1810	1420	1140	1090	1110	1060	1370	1500
1640	1760	1870	[illegible]	980	1250	[illegible]	1060	1110	[illegible]	1360
1450	1640	1310	1280	1200	1110	[illegible]	1250	[illegible]	[illegible]	1030

RUN 2 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
2260	2650	2310	2700	3430	2980	1170	1170	1200	1310	1980
1980	2260	2140	2060	1700	1700	1250	1140	1250	1420	1530
1980	1900	1810	1870	1420	1250	1200	1140	1230	1700	1700
1700	1780	1840	1670	1640	1280	1370	1390	1140	1090	1500
1280	1340	1280	1250	1170	1390	1280	1140	1170	1250	1230

```
RUN  3     REPLICATE  1
218.0  *  173.5  *  132.5  *  91.5  *  50.5  *  15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1660 1690 1580 1440 1990 1550 1940 1440 1660 1270 1210
1690 1630 1630 1440 1470 1470 1330 1270 1270 1330 1350
1630 1660 1490 1520 1490 1330 1330 1380 1470 1410 1440
1660 1690 1580 1520 1380 1520 1470 1520 1580 1550 1580
1600 1690 1630 1630 1520 1520 1490 1520 1580 1580 1630
RUN  3     REPLICATE  2
218.0  *  173.5  *  132.5  *  91.5  *  50.5  *  15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1710 1820 1710 1570 2160 1600 1820 1570 1240 1350 1290
1050 1770 1680 1630 1680 1650 1460 1350 1350 1430 1460
1710 1890 1650 1630 1520 1460 1460 1570 1520 1600 1600
1790 1790 1660 1650 1570 1680 1570 1650 1630 1690 1630
1790 1740 1680 1680 1650 1600 [illegible] 1630 1710 1740 1660
RUN  3     REPLICATE  3
218.0  *  173.5  *  132.5  *  91.5  *  50.5  *  15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1780 1780 1620 1700 2140 1590 1810 1450 1230 1370 1250
1780 1780 1620 1640 1670 1560 1420 1340 1390 1480 1450
1730 1730 1590 1700 1640 1500 1620 1500 1560 1560 1590
1760 1760 1620 1620 1590 1620 1640 1620 1620 1640 [illegible]
1780 1730 1760 1670 1730 1640 1640 1730 1670 1640 1730
RUN  4     REPLICATE  1
218.0  *  173.5  *  132.5  *  91.5  *  50.5  *  15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1830 1440 1550 1990 2110 1460  840  940  940  930 [illegible]
1300 1580 1470 1410 1330  940  850  850  910 1050 [illegible]
1300 1270 1210 1300 1050  990  910  940  880 1300 1160
1300 1100 1190  990  910 1050  960  960  820  740 1240
1130 1080 1130 1050  990 1020  950  940  940  960  960
RUN  4     REPLICATE  2
218.0  *  173.5  *  132.5  *  91.5  *  50.5  *  15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1410 1490 1630 1800 2020 1470  800  910  940  990 1580
1330 1270 1410 1470  960  850  770  820  940 1020 1190
1350 1270 1300 1410  960  960  830  880  850 1550 1270
1130 1100 1160 1080  960  940  850 1020  800  960 1210
1050 1270  990 1130  990  910  850  940  940  910  960
RUN  4     REPLICATE  3
218.0  *  173.5  *  132.5  *  91.5  *  50.5  *  15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1870 1640 1560 1980 2200 1480  840  810  890 1000 1250
1280 1230 1310 1420 1090  860  810  840  950  950 1060
1370 1140 1170 1200 1060  890  810  810 1000 1060 1090
1350 1140 1170 1170 1000  890  980  920  890  810 1300
1640 1640 1500 1560 1310 1450 1450 1420 1280 1370 1310
```

RUN 5 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
990	940	1050	910	[illegible]	960	1020	[illegible]	[illegible]	[illegible]	[illegible]
960	960	1020	910	1050	850	770	890	[illegible]	740	[illegible]
960	960	880	1020	940	710	710	660	690	740	850
990	990	960	800	770	740	770	740	800	850	800
990	960	960	880	960	850	850	850	850	880	880

RUN 5 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1060	1060	1090	1000	1700	1060	1200	950	720	720	640
1140	1110	980	1000	1090	1000	860	720	720	720	810
1060	1060	1110	1060	980	890	750	780	810	890	890
1110	1060	1060	1060	890	810	890	890	890	950	950
1110	1110	1060	1000	1000	860	890	950	950	980	1000

RUN 5 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1090	1000	1140	1030	1760	1000	1310	840	700	670	700
1030	1030	1030	1110	1090	950	840	720	720	750	750
1000	1030	980	860	810	840	750	750	750	810	840
1110	1030	[illegible]	980	890	840	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1110	1060	1060	890	950	890	920	920	920	980	810

RUN 6 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1630	1630	1960	1910	790	790	680	740	740	760	820
1230	1210	1290	1070	850	650	710	710	650	870	[illegible]
1180	1400	1180	900	680	710	740	710	680	900	870
1100	1150	1100	900	820	750	760	850	620	620	900
990	1040	870	1070	930	760	870	760	850	760	680

RUN 6 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1310	1310	2140	1700	1530	780	670	700	700	780	840
1340	1310	1250	1200	750	700	700	750	750	780	860
1140	1200	1370	920	750	750	780	720	810	780	810
1090	1060	1090	1060	810	840	840	840	750	700	890
1090	1000	1000	840	860	950	950	920	890	890	780

RUN 6 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
1030	1420	1640	1760	1420	670	670	670	700	750	810
1230	1250	1200	1420	700	750	700	670	810	810	810
1200	1170	1250	1140	860	700	750	670	720	810	860
1110	1110	1140	860	780	810	750	810	670	730	[illegible]
890	1060	980	1000	860	920	860	860	840	860	810

```
RUN  7      REPLICATE  1
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1000 1050 1140 1000  770 1000 1190  910  660  800  660
1000 1110  910  970  910  970  830  720  720  720  800
1030 1140  910 1000 1000 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
1050 1080  940  940  910  860  830  970  970  940  890
1050 1050 1000 1000  970  890  910  940  940  940  940
RUN  7      REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1000 1000 1370 1000 1370  950 1110  840  700  720  670
1030 1110  950  980  980  890  810  720  700  730  730
1090 1000 1060  980  980  920  720  700  750  890  890
1090 1110  950  920  840  840  840  920  950  950  890
1030 1030  980  980  920  920  920  920  980  950  840
RUN  7      REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1090 1060 1030 1060 1370 1030 1110  890  720  700  750
1030 1060  980  920  950  920  920  640  750  750  810
1030 1030  840  890  950  890  750  750  810  860  840
1090  980  950  920  860  840  840  920  950  920  920
1090 1090 1060  950 1060  890  950  920  890  890  920
RUN  8      REPLICATE  1
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1110 1450 1280 1670 1340  590  700  640  610  720  840
1110 1110 1060 1110  810  610  610  560  720  720  700
 980  780  890  840  700  700  700  560  670  700  840
 810  920  860  840  670  720  700  700  670  670  750
 860  840  750  840  720  700  720  780  780  730  720
RUN  8      REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 950 1370 1420 1530  980  780  610  610  670  720  810
 890 1090 1090  810  640  640  640  670  670  700  840
1060  860  860  920  670  700  670  590  610  730  730
 840  840  860  750  640  590  720  720  560  530  810
 860  840  750  750  750  780  780  750  720  700  720
RUN  8      REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
1170 1480 1420 1420 1480  890  700  670  700  730  810
1000 1140 1000 1090  670  670  670  670  720  810  780
1090 1140 1090  840  700  700  720  610  780  730  780
 890  840  830  700  700 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 840  840  830 [illegible]  940 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
```

RUN 9 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
550	550	800	630	850	430	380	350	380	380	380
550	520	630	570	630	380	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
490	520	520	520	410	380	410	410	380	430	360
490	490	520	490	410	410	380	460	410	350	380
460	490	490	420	430	420	430	430	430	430	410

RUN 9 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
540	400	870	670	510	400	370	340	400	430	370
510	510	510	510	400	400	380	450	400	400	400
480	560	620	370	400	400	340	370	400	400	420
450	510	560	400	400	420	370	400	370	370	370
450	420	450	450	450	420	400	450	510	480	400

RUN 9 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
500	610	750	700	560	450	390	360	360	390	390
450	500	560	590	360	390	390	360	360	390	390
500	470	560	420	390	390	390	390	360	420	450
470	530	560	450	390	450	450	420	390	330	390
450	500	530	470	450	450	450	420	450	450	390

RUN 10 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
540	600	900	790	570	430	570	370	370	400	460
570	620	600	510	490	370	370	370	430	400	430
570	570	570	490	400	370	400	320	400	400	370
510	510	510	460	430	400	400	460	460	370	460
490	460	490	510	460	460	460	460	430	430	430

RUN 10 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
520	600	800	850	490	350	380	350	350	380	460
490	550	350	490	380	380	320	350	410	430	460
490	560	550	550	380	410	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
570	460	460	430	380	350	380	410	380	330	430
460	490	490	490	460	410	430	430	430	330	330

RUN 10 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
550	[illegible]	560	[illegible]	630	[illegible]	350	320	350	410	[illegible]
550	570	570	570	380	380	350	350	380	330	410
520	490	490	490	380	380	330	350	350	410	410
490	430	490	410	410	380	410	410	320	320	[illegible]
460	490	520	490	430	460	410	430	410	330	410

RUN 11 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
530	560	590	640	640	390	370	330	360	[illegible]	[illegible]
560	530	500	500	500	360	[illegible]	360	360	420	[illegible]
470	450	500	390	390	360	360	330	420	420	420
450	420	360	390	420	420	390	390	330	420	420
470	470	450	390	390	450	450	420	420	390	390

RUN 11 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
540	570	740	650	510	400	400	370	370	490	490
510	620	650	510	430	400	400	400	430	460	460
570	570	510	460	430	400	400	400	400	430	460
510	540	460	460	460	460	460	490	370	430	460
540	570	510	510	510	460	510	490	490	400	430

RUN 11 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
470	640	750	530	500	470	330	390	360	450	470
500	640	560	360	390	390	390	360	390	360	450
500	500	470	430	390	390	360	360	330	450	420
500	420	470	390	450	420	450	470	330	330	450
470	470	470	420	470	390	420	420	430	420	450

RUN 12 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
520	570	800	910	520	410	520	350	320	380	430
430	490	520	520	350	380	350	350	[illegible]	410	410
460	520	490	570	350	350	350	380	350	380	410
490	430	430	410	380	380	410	410	300	350	430
380	410	430	410	410	350	410	410	380	410	350

RUN 12 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
500	500	530	530	700	780	1340	1200	1310	1200	1170
470	500	530	530	560	560	750	1060	1090	1140	1090
530	500	500	560	500	560	780	860	980	1170	1090
560	530	500	470	530	560	590	560	810	840	950
560	560	500	500	530	500	500	500	560	420	420

RUN 12 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
560	530	750	860	860	310	310	310	330	390	390
420	500	560	420	330	330	310	310	330	390	390
450	500	560	390	330	330	330	310	360	330	360
390	420	390	[illegible]	330	330	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
390	390	420	420	390	390	360	360	390	330	330

APPENDIX V

TEMPERATURE DATA (AMMONIA)

The temperature data collect during the experiment with ammonia for all the combinations of the independent variables are presented in the following pages. In this case only Replicates two and three are presented.

In the heading to each section, the Run and Replicate number are given. The Run number corresponds to the Experimental Run number in Appendix II.

The columns in each section correspond to the distances from inlet and the rows to the heights from floor. Every other column is given its appropriate heading of distance from inlet (inches). Reference can be made to Figure 10 for the column headings not included. The rows in each section correspond to the heights from floor. Starting at the top row these correspond to the one foot, two feet, three feet, five feet and seven feet heights from floor.

RUN 1 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	75.0	92.0	[illegible]	[illegible]	75.0	[illegible]	[illegible]	74.5	[illegible]	[illegible]
76.5	75.5	78.5	76.5	77.0	75.5	75.0	74.5	75.0	75.0	75.0
76.5	76.0	78.0	75.5	76.5	77.0	73.5	75.0	75.5	75.0	75.0
76.5	76.0	76.5	76.5	76.0	75.5	75.5	76.0	75.5	75.5	75.5
75.0	76.0	76.0	77.0	76.5	76.0	75.5	75.5	75.5	76.0	76.0

RUN 1 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
73.0	73.5	97.0	74.5	82.0	74.5	81.5	75.0	73.5	73.0	72.0
74.5	75.0	76.5	76.0	76.5	76.0	75.5	74.5	74.0	74.0	74.0
75.0	75.5	77.0	77.0	76.5	76.0	75.5	75.5	75.5	75.5	75.0
75.0	75.5	76.5	76.0	76.0	76.0	76.0	76.0	76.0	76.0	76.0
75.5	76.0	76.5	76.5	76.0	76.0	76.0	76.5	76.5	76.5	76.5

RUN 2 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
73.0	72.0	72.0	72.0	72.5	72.0	72.0	73.0	72.0	72.0	72.0
72.0	72.5	73.5	72.0	72.5	72.0	72.5	72.0	73.0	72.0	72.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72.5	73.0	73.0	72.0	72.0	72.0
[illegible]	[illegible]	72.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72.0	[illegible]	[illegible]
72.0	72.0	72.0	73.0	73.0	72.0	73.0	72.0	72.0	73.0	72.0

RUN 2 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	71.5	72.0	71.5	71.5	71.0	[illegible]	[illegible]	72.0	71.5	[illegible]
72.0	72.0	72.0	71.5	71.5	71.5	71.0	71.5	71.0	71.0	71.5
72.0	72.0	71.0	71.5	71.5	71.0	71.5	71.5	71.0	71.5	71.5
71.5	71.5	71.5	71.5	71.5	72.0	72.0	72.0	71.0	71.5	71.0
71.5	71.5	71.5	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

RUN 3 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
77.0	76.5	93.0	77.0	86.0	76.0	80.0	76.8	74.5	74.0	74.0
77.0	76.0	78.0	76.5	78.0	77.0	76.0	74.5	75.0	75.0	75.0
76.0	77.0	78.0	76.0	76.9	76.0	75.0	76.0	76.5	76.0	76.0
76.5	76.5	76.5	76.5	76.0	76.0	77.0	77.0	76.5	76.0	76.0
[illegible]	[illegible]	[illegible]	76.5	[illegible]	76.5	75.5	76.5	76.0	76.5	76.0

RUN 3 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
71.5	72.5	95.0	73.5	72.0	75.0	78.5	77.0	76.5	74.5	73.5
75.0	76.0	77.5	77.5	77.5	77.0	76.5	75.5	75.0	75.0	75.0
77.0	77.0	77.5	77.0	77.5	76.5	76.0	76.0	76.0	76.0	76.0
[illegible]	[illegible]	77.5	77.0	77.0	77.0	[illegible]	77.0	[illegible]	[illegible]	77.0
76.5	77.0	77.0	77.0	76.5	76.5	76.5	77.0	77.0	77.0	77.0

```
RUN  4     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   [illegible]  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 72.0 72.0 72.0 72.0 73.0 71.0 [illegible] 72.0 71.0 72.[illegible]
[illegible] 72.0 72.0 72.0 72.5 72.5 72.5 72.5 71.5 72.0 72.0
72.[illegible] 72.0 73.0 72.0 72.0 72.[illegible] 72.0 72.0 71.5 72.0 73.0
74.0 72.5 72.0 72.0 72.0 72.0 72.5 72.0 71.0 72.5 72.0
72.0 71.5 71.5 71.0 72.[illegible] 71.5 72.5 72.0 72.0 72.5 72.0
RUN  4     REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 72.0 72.0 72.0 72.0 72.[illegible] 72.[illegible] 72.0 72.0 72.0 72.0
72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0
72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0
72.0 72.0 72.0 73.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0
72.0 72.0 72.0 72.0 72.0 72.0 72.[illegible] 72.0 72.0 72.0 72.0
RUN  5     REPLICATE  [illegible]
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
73.0 73.5 93.0 73.0 83.0 74.0 76.[illegible] 73.5 71.5 71.[illegible] 71.5
7[illegible] 73.5 76.5 73.5 73.5 73.[illegible] 73.0 72.0 71.0 72.0 72.0
74.5 73.5 75.5 73.0 73.[illegible] 72.5 72.[illegible] 72.0 72.5 73.0 72.0
7[illegible] 73.5 73.0 73.5 73.5 72.5 72.[illegible] 74.0 72.5 73.[illegible] 72.5
73.[illegible] 73.0 74.5 74.0 74.0 72.[illegible] 72.[illegible] 74.[illegible] 73.[illegible] 73.[illegible] 73.0
RUN  5     REPLICATE  3
21[illegible]  *  17[illegible]  *  13[illegible].5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
73.5 7[illegible] 92.0 74.5 [illegible] 74.0 76.5 74.5 72.0 71.0 7[illegible].5
7[illegible] 72.[illegible] 76.0 75.0 73.5 74.5 73.0 72.0 72.0 72.0 71.5
72.[illegible] 7[illegible] 74.0 75.0 74.0 74.0 71.0 72.0 72.0 71.5 72.0
73.[illegible] 7[illegible] 74.5 73.5 73.5 73.0 74.[illegible] 73.0 73.0 73.5 73.5
73.5 73.5 74.5 74.5 74.0 73.5 72.5 73.5 74.0 73.5 73.5
RUN  [illegible]     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 72.0 72.0 72.0 72.0 72.0 72.0 71.5 72.0 72.0 72.0
72.0 72.0 72.5 72.0 72.0 72.0 72.0 72.0 72.5 72.0 72.0
72.0 72.5 72.5 72.0 72.0 72.5 72.0 72.0 72.0 72.0 72.0
71.5 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 73.0
72.0 72.0 72.[illegible] 72.[illegible] 72.0 72.[illegible] 72.0 72.0 72.5 72.5 73.0
RUN  [illegible]     REPLICATE  3
218.0  *  173.5  *  13[illegible]  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0
72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 71.0
72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0
72.[illegible] 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.[illegible] 72.[illegible] 72.0
72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 73.0 72.0 72.0
```

RUN 7 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
73.0	74.0	83.0	72.0	83.0	74.5	76.5	74.5	72.0	71.0	72.0
75.[illegible]	74.5	75.5	74.5	75.0	74.[illegible]	73.[illegible]	72.[illegible]	73.0	72.0	73.[illegible]
[illegible]	75.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	74.0	73.0	73.[illegible]
75.0	75.0	75.[illegible]	73.0	73.[illegible]	74.5	73.5	73.5	73.0	74.5	73.[illegible]
74.5	75.0	73.5	74.5	73.0	74.0	74.0	73.5	74.0	74.0	73.5

RUN 7 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.5	73.5	95.0	73.0	82.0	74.0	77.5	74.5	71.0	70.5	70.0
72.0	73.0	75.5	74.5	74.5	73.5	72.5	72.0	71.0	71.0	71.0
72.0	73.5	73.5	73.5	73.5	72.0	72.0	71.5	72.0	72.0	71.5
73.0	73.5	73.5	73.5	73.0	73.0	72.0	73.0	73.0	73.5	73.0
73.0	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.0	73.0	74.0

RUN 8 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.0	72.0	72.0	72.0	72.0	71.5	72.0	72.0	72.0	72.0	71.0
72.0	72.0	71.5	72.0	72.0	72.0	72.0	71.5	72.0	72.0	72.0
72.0	72.0	71.5	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0
72.0	72.0	71.5	72.0	71.5	71.5	72.0	71.5	72.0	72.0	72.0
72.[illegible]	72.0	72.[illegible]	72.[illegible]	71.[illegible]	72.0	72.[illegible]	72.[illegible]	72.[illegible]	[illegible]	72.[illegible]

RUN 8 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	71.5
72.0	72.0	72.0	72.0	72.0	72.0	71.5	72.0	72.0	71.0	72.0
72.0	72.0	72.5	72.0	72.0	72.0	71.0	72.0	72.0	72.0	72.0
72.0	72.0	72.0	72.0	71.5	72.0	71.0	72.0	72.0	71.5	72.0
71.5	72.0	72.0	71.0	72.0	71.0	71.0	72.0	72.0	72.0	72.0

RUN 9 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
73.0	72.0	82.0	73.0	75.0	71.0	71.0	70.5	70.5	71.0	71.0
72.0	73.0	73.5	73.0	72.0	71.0	71.0	71.0	71.0	71.0	71.0
72.0	72.0	73.0	72.5	72.0	71.5	71.5	72.0	70.5	71.5	71.0
71.5	72.0	73.0	71.5	72.0	71.0	71.5	72.0	71.0	69.5	72.0
71.5	72.0	72.0	71.5	72.0	72.0	72.0	71.0	72.0	71.0	72.0

RUN 9 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
71.5	72.5	83.0	72.0	74.0	72.0	71.0	71.0	71.0	71.0	71.5
72.5	71.5	72.0	72.5	72.0	71.0	71.0	70.5	71.0	71.5	71.5
72.5	72.0	73.0	72.0	71.0	71.5	71.5	70.5	70.5	71.0	70.5
72.[illegible]	72.[illegible]	72.5	71.5	71.[illegible]	71.5	72.0	72.0	70.5	69.0	71.0
72.5	72.[illegible]	[illegible]	72.[illegible]	[illegible]	[illegible]	71.5	72.0	72.[illegible]	72.[illegible]	71.5

RUN 10 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.0	72.0	72.0	71.5	72.0	72.0	72.0	71.5	72.0	72.0	72.0
72.0	72.0	72.0	72.0	72.0	72.0	72.0	71.5	72.0	71.5	72.0
71.5	72.0	72.0	71.5	72.0	71.5	71.5	72.0	72.0	72.0	72.0
71.5	72.0	71.5	72.0	72.0	72.0	72.0	72.0	71.5	71.5	71.5
72.0	72.0	72.0	72.0	72.0	72.0	71.5	72.0	72.0	71.5	71.5

RUN 10 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
71.5	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0
72.0	71.5	72.0	72.0	71.5	72.0	72.0	72.0	72.0	72.0	72.0
72.0	72.0	72.0	72.0	72.0	71.5	72.0	72.0	72.0	72.0	72.0
[illegible]	[illegible]	72.0	[illegible]	72.0	72.0	71.5	71.5	[illegible]	[illegible]	72.0
71.5	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

RUN 11 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.0	72.5	82.0	74.0	75.0	71.5	75.0	70.5	71.0	72.0	71.5
71.5	73.0	72.5	72.0	71.5	71.5	71.5	71.0	71.5	71.0	71.0
72.0	73.0	72.5	72.0	71.0	72.0	71.5	71.0	71.0	71.5	71.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71.5	71.5	[illegible]	[illegible]	69.0	71.0
[illegible]	[illegible]	[illegible]	71.5	[illegible]	71.5	[illegible]	72.5	[illegible]	72.0	[illegible]

RUN 11 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71.5	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72.0	71.0	70.5	71.0	71.0
71.5	72.0	72.0	72.0	72.0	71.5	71.0	71.0	70.5	71.0	71.0
72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	71.0	69.0	70.5
71.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

RUN 12 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	71.0	72.0
72.0	72.0	72.0	72.0	72.0	72.5	72.0	72.0	72.0	72.0	72.0
72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	71.0	72.0	71.0
72.0	72.0	71.0	72.0	71.0	72.0	72.0	72.0	72.0	72.0	72.0
72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	71.5	72.0	72.0

RUN 12 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
71.5	71.0	71.5	71.0	71.5	71.0	71.0	71.0	71.5	71.0	71.0
71.0	71.0	71.5	71.5	71.0	71.0	71.5	71.5	71.5	71.0	71.0
71.5	71.0	71.0	71.0	71.5	71.0	71.0	71.5	71.5	71.5	71.0
[illegible]	71.0	71.0	71.0	71.0	71.0	71.0	71.5	71.5	71.5	71.0
[illegible]	71.0	71.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	71.0	[illegible]	[illegible]

APPENDIX VI

TEMPERATURE DATA (CARBON DIOXIDE)

The temperature data collected during the experiment with carbon dioxide for all the combinations of the independent variables are presented in the following page.

In the heading to each section, the Run and Replicate number are given. The Run number corresponds to the Experimental Run number in Appendix II.

The columns in each section correspond to the distances from inlet and the rows to the heights from floor. Every other column is given its appropriate heading of distance from inlet (inches). Reference can be made to Figure 10 for the column headings not included. The rows in each section correspond to the heights from floor. Starting at the top row these correspond to the one foot, two feet, three feet, five feet and and seven feet heights from floor.

```
 RUN  1     REPLICATE  1
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 [illegible] 77.5 82.5 77.0 85.5 77.0 81.5 77.0 74.0 75.5 [illegible]
 77.0 77.5 80.0 77.0 77.5 76.5 77.5 75.5 75.0 77.0 74.5
 78.0 76.0 78.5 77.5 77.5 76.0 76.0 77.5 77.0 76.5 [illegible]
 78.0 77.5 79.0 77.0 76.5 77.0 77.0 76.5 77.0 75.0 76.5
 77.0 77.0 77.5 77.5 77.0 75.0 77.0 77.5 77.0 77.0 [illegible]
 RUN  1     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 76.0 76.5 94.0 77.5 89.0 76.5 83.0 76.5 [illegible] [illegible] [illegible]
 76.5 77.0 77.5 77.0 78.5 76.5 75.0 75.0 75.0 75.0 74.5
 77.5 76.5 78.5 77.0 78.0 76.0 75.0 74.5 76.0 75.5 75.5
 76.5 78.0 78.0 77.5 77.0 76.5 77.0 77.0 [illegible] [illegible] [illegible]
 77.5 77.0 77.5 77.5 77.0 76.5 76.5 77.5 [illegible] [illegible] [illegible]
 RUN  1     REPLICATE  [illegible]
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 [illegible]
 [illegible]
 [illegible]
 [illegible]
 [illegible]
 RUN  [illegible]     REPLICATE  [illegible]
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 [illegible]
 [illegible]
 74.5 73.5 73.0 73.0 76.0 75.5 73.5 [illegible] [illegible] [illegible] [illegible]
 [illegible]
 74.5 74.5 73.5 74.5 74.0 74.0 74.0 73.5 74.5 74.0 73.5
 [illegible]
 [illegible]
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 72.5 74.0 73.0 72.5 73.0 72.5 72.5 72.5 72.5 72.5 72.5
 72.5 72.5 72.5 72.5 73.0 73.0 72.5 72.5 72.5 73.0 72.5
 72.5 72.5 72.5 73.0 72.5 72.5 72.0 72.5 72.5 72.5 72.0
 72.5 73.0 72.5 72.5 72.5 72.5 72.5 72.5 72.0 72.5 71.5
 [illegible] [illegible] [illegible] [illegible] [illegible] 72.5 72.5 72.5 72.5 72.5 [illegible]
 RUN  2     REPLICATE
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 72.0 73.0 72.5 72.5 72.5 72.5 72.5 72.0 72.0 72.5 72.5
 72.5 72.5 72.0 72.0 73.0 72.5 72.5 72.0 72.5 72.0 72.0
 [illegible] [illegible] 73.0 72.5 72.0 72.5 [illegible] [illegible] [illegible] [illegible] [illegible]
 72.5 72.0 72.5 72.5 72.5 72.5 72.0 72.5 72.0 71.5 72.5
 72.5 72.5 73.0 72.5 72.0 73.0 72.5 72.5 73.0 73.0 72.5
```

```
 RUN  3     PEPLICATE  1
218.0  *  173.5  *  132.5  *   91.5  *   5[illegible].5  *   15.[illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
77.0 77.0 79.5 76.5 89.[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] 78.0 80.0 74.5 78.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
77.0 78.5 78.0 77.5 77.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
77.5 77.5 78.5 77.5 79.[illegible] [illegible] 77.0 [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] 77.5 [illegible] [illegible] 77.5 [illegible] [illegible] [illegible]
 RUN  3     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.[illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
76.5 76.5 95.0 77.0 89.0 77.0 83.0 77.0 75.0 73.5 73.5
77.5 77.5 81.0 77.0 79.0 77.0 76.5 75.0 74.5 74.5 75.5
77.5 78.0 78.5 78.0 77.0 77.0 76.0 75.0 76.5 76.5 76.5
78.0 78.0 77.5 77.5 77.0 77.0 77.0 77.0 77.5 77.5 77.0
78.0 77.5 77.5 77.0 76.5 77.5 77.5 77.5 76.5 77.5 76.0
 RUN  3     REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
77.0 77.0 94.0 77.5 90.0 76.5 82.0 77.5 [illegible] [illegible] [illegible]
77.5 78.0 78.5 78.5 78.5 77.0 76.0 75.[illegible] [illegible] [illegible] [illegible]
78.0 78.5 79.0 77.5 77.5 76.5 76.5 7[illegible].5 [illegible] [illegible] [illegible]
[illegible] 78.0 78.0 77.0 77.0 77.5 78.0 [illegible] [illegible] [illegible] [illegible]
77.0 77.5 79.0 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 RUN  4     REPLICATE  1
[illegible].0  *  173.5  *  132.5  *   91.5  *   5[illegible].5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 73.5 [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 72.5 [illegible] [illegible]
[illegible] [illegible] [illegible] 72.5 73.0 72.0 73.0 72.5 72.5 73.0 [illegible]
72.5 73.5 72.5 73.0 72.5 73.0 72.5 73.0 73.5 72.5 73.[illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 RUN  4     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.[illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
[illegible] [illegible] [illegible] 72.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 RUN  [illegible]     [illegible]PLICATE  3
[illegible]  *  [illegible]  *  [illegible]  *   [illegible]  *   [illegible]  *   [illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
```

```
 RUN   5      REPLICATE  1
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 74.0 73.0 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 [illegible] [illegible] 77.0 75.[illegible] [illegible] [illegible] [illegible] 72.5 71.5 [illegible] [illegible]
 76.0 74.[illegible] 76.5 74.0 [illegible] 74.0 73.5 70.5 72.0 74.0 [illegible]
 75.[illegible] 74.0 75.5 73.5 [illegible] 73.0 73.0 75.0 73.0 74.5 74.[illegible]
 [illegible] 75.0 74.5 76.5 74.5 72.0 73.5 74.0 73.5 74.0 73.5
 RUN   5      REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 73.5 74.5 [illegible] [illegible] [illegible] 74.5 80.0 73.5 [illegible] 71.[illegible] [illegible]
 74.0 74.0 [illegible] [illegible] [illegible] 75.0 73.0 71.5 [illegible] 72.[illegible] [illegible]
 74.[illegible] 74.[illegible] [illegible] [illegible] [illegible] 73.5 72.5 71.0 72.0 72.5 [illegible]
 75.0 74.5 76.0 [illegible] [illegible] 73.0 73.5 73.5 73.5 73.[illegible] [illegible]
 75.[illegible] 74.5 75.0 [illegible] [illegible] 74.0 73.5 74.0 74.0 73.5 73.5
 RUN   5      REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 [illegible] 73.5 92.0 [illegible] [illegible] 75.0 80.0 74.5 72.0 71.0 71.5
 74.0 74.5 81.0 74.5 [illegible] 74.5 73.5 72.0 72.0 72.0 72.[illegible]
 74.5 74.0 75.5 75.0 [illegible] 73.0 72.5 71.5 72.5 72.5 72.[illegible]
 76.5 75.0 74.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 75.0 74.0 75.0 74.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 RUN   6      REPLICATE  1
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 72.[illegible] [illegible] [illegible] 72.0 72.5 [illegible] [illegible] 72.5 [illegible] [illegible] [illegible]
 72.5 [illegible] 72.5 72.0 72.[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 72.0 73.0 74.5 72.5 72.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 72.[illegible] 72.0 72.0 72.5 72.[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
 72.[illegible] 74.5 72.5 72.5 72.5 72.5 72.0 72.0 72.0 72.5 72.[illegible]
 RUN   6      REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 72.0 72.[illegible] [illegible] 71.5 72.[illegible] 72.5 71.5 73.0 [illegible] [illegible] [illegible]
 73.[illegible] 72.5 72.[illegible] [illegible] 72.[illegible] 72.0 72.5 72.0 [illegible] 72.[illegible] [illegible]
 73.[illegible] 72.5 72.[illegible] 72.0 72.[illegible] 72.5 71.5 71.5 71.5 [illegible] [illegible]
 72.[illegible] 72.0 [illegible] 72.0 72.0 72.0 72.0 72.5 72.5 72.[illegible] [illegible]
 [illegible] [illegible] 73.[illegible] [illegible] 72.5 73.0 71.5 72.5 72.0 73.0 73.[illegible]
 RUN   6      REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
 ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
 72.[illegible] 72.[illegible] [illegible] 73.0 72.0 71.5 72.0 72.0 72.0 72.0 71.5
 72.0 [illegible] [illegible] 72.0 72.0 72.0 72.0 72.0 72.0 71.5 71.5
 72.[illegible] 72.[illegible] 72.[illegible] 71.5 72.0 73.0 72.5 72.0 72.0 72.0 71.5
 72.5 72.0 [illegible] [illegible] 72.0 [illegible] [illegible] [illegible] 71.5 [illegible] [illegible]
 [illegible] 72.[illegible] [illegible] [illegible] 71.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
```

```
RUN  7     REPLICATE  1
[illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
[illegible]
[illegible]
[illegible]
[illegible]
75.0 75.5 75.5 75.0 75.0 74.0 74.5 74.5 74.5 74.0 73.[illegible]
RUN  7     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
74.0 75.5 89.0 74.0 89.0 74.5 82.0 74.5 72.0 71.0 70.[illegible]
74.5 75.5 76.5 75.0 74.5 74.5 74.0 72.5 71.0 71.5 72.[illegible]
74.5 75.5 75.5 75.0 74.5 73.0 72.5 72.5 72.0 73.5 72.5
75.0 75.0 75.5 75.0 73.5 72.5 73.5 74.0 73.5 74.0 72.5
73.0 75.0 75.5 75.0 75.0 73.5 74.5 73.5 73.5 74.5 73.5
RUN  7     REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
73.5 74.5 87.0 74.5 86.0 74.5 78.0 73.5 72.5 71.0 71.0
74.5 76.0 76.5 74.5 75.5 75.0 73.0 72.5 71.5 72.0 72.5
75.0 75.0 75.0 74.5 74.0 74.5 72.5 72.5 72.0 74.0 72.5
[illegible] [illegible] [illegible] 74.5 73.5 73.5 [illegible] 73.5 74.5 73.5 73.[illegible]
75.0 74.5 74.0 74.0 75.0 74.5 74.5 73.5 73.5 73.5 73.0
RUN  8     REPLICATE  1
[illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
75.0 74.5 74.5 74.5 74.0 74.0 74.5 74.0 74.5 74.5 74.5
74.5 74.5 74.5 74.0 74.5 74.5 75.0 75.0 75.0 74.5 74.5
74.5 74.5 74.5 75.0 75.0 75.0 74.5 74.5 74.5 74.0 74.5
74.0 74.5 75.0 74.5 75.0 74.5 75.0 75.0 75.0 75.0 75.0
74.5 74.5 74.0 75.0 75.0 74.5 74.5 75.0 74.5 74.5 75.[illegible]
RUN  8     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.[illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 73.0 72.0 72.0 72.0 72.0 72.5 71.5 72.5 71.5 72.0
72.0 72.0 72.0 72.0 72.0 71.5 71.5 71.5 72.0 72.0 72.0
72.0 72.0 72.0 72.0 72.5 72.5 72.0 71.5 72.5 72.5 72.5
72.5 72.0 71.5 72.0 72.5 72.5 72.5 73.0 72.0 71.5 72.0
72.5 72.0 72.5 72.0 71.5 72.0 72.5 73.0 73.0 72.0 72.5
RUN  8     REPLICATE  3
[illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
[illegible]
72.5 72.5 73.0 72.5 72.5 73.0 73.0 72.5 73.0 72.5 72.0
72.5 73.0 72.5 72.0 73.0 72.5 73.0 72.5 73.0 72.5 72.5
[illegible]
73.0 73.0 73.5 72.5 73.0 72.5 72.5 73.0 73.0 73.0 72.5
```

```
RUN  9     REPLICATE  1
[illegible] * 173.5 * [illegible] * [illegible] * [illegible] * [illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
[illegible]
[illegible]
[illegible]
[illegible]
72.5 72.5 73.0 73.0 73.0 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
RUN  9     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.5 73.0 80.0 75.0 74.0 72.5 70.5 70.5 71.0 71.5 71.5
72.5 72.5 72.5 73.0 71.5 72.0 71.0 71.0 71.5 72.0 72.0
72.5 73.0 73.5 72.0 72.0 72.0 71.5 71.0 71.5 71.5 70.5
72.0 73.0 72.5 71.5 72.5 71.5 72.5 71.0 70.5 69.5 72.0
72.5 72.0 72.5 72.5 72.0 72.5 72.0 72.5 72.5 72.5 71.5
RUN  9     REPLICATE  3
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 72.0 81.0 75.0 74.0 72.5 72.0 70.0 70.5 71.0 71.0
72.5 73.5 73.5 73.0 72.5 71.5 71.0 71.0 70.5 72.0 71.5
72.0 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
73.0 73.0 73.0 72.5 [illegible] [illegible] [illegible] [illegible] 71.0 69.5 71.5
72.5 72.5 72.5 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
RUN 10     REPLICATE  1
218.0  *  173.5  *  132.5  *  [illegible] * [illegible] * [illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
[illegible]
72.0 72.5 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0
72.5 72.5 72.0 72.0 72.0 72.0 72.0 72.0 72.5 72.0 72.5
72.0 72.5 72.5 72.0 72.0 72.0 72.0 72.0 72.0 71.5 72.0
72.0 72.5 72.5 72.0 72.0 72.0 72.5 72.5 72.0 72.5 72.0
RUN 10     REPLICATE  2
218.0  *  173.5  *  132.5  *   91.5  *   50.5  *   15.0
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 72.0 72.0 72.5 72.5 71.5 72.5 72.5 72.0 72.0 72.0
72.0 72.5 72.5 72.0 72.0 73.0 72.5 73.0 72.5 72.5 72.0
72.0 72.0 73.0 72.5 72.0 72.0 71.5 72.0 72.5 72.0 71.5
73.0 72.0 72.0 72.5 72.0 72.0 71.5 72.0 72.5 71.5 [illegible]
72.0 72.5 72.5 72.0 72.5 71.5 72.5 72.5 72.5 71.5 72.0
RUN 10     REPLICATE  3
[illegible] * 173.5 * [illegible] * [illegible] * [illegible] * [illegible]
---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
72.0 71.5 72.0 72.0 71.5 72.0 72.0 72.0 71.5 72.0 72.0
72.0 72.0 72.0 72.0 72.0 71.5 72.0 71.5 72.0 72.0 72.0
72.5 72.0 72.0 71.5 72.0 72.0 71.5 72.0 72.0 72.0 72.0
[illegible] [illegible] 72.0 72.0 72.5 72.0 71.5 72.0 72.0 71.5 72.0
72.0 72.0 72.5 72.0 72.0 72.0 72.0 72.0 72.0 72.0 72.0
```

RUN 11 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
73.0	74.0	81.0	76.0	78.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
72.5	74.5	[illegible]	[illegible]	72.5	[illegible]	71.5	[illegible]	[illegible]	[illegible]	[illegible]
73.5	73.5	72.5	72.0	74.0	72.0	72.5	71.5	[illegible]	[illegible]	[illegible]
73.8	72.5	74.0	72.5	72.5	73.0	72.0	72.0	[illegible]	[illegible]	[illegible]
72.0	72.0	72.5	73.0	72.5	72.0	72.5	72.5	[illegible]	[illegible]	[illegible]

RUN 11 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.0	73.5	81.5	75.5	75.0	72.0	72.0	70.5	72.0	71.5	72.0
73.0	74.5	75.0	72.5	71.5	72.0	71.0	70.5	72.0	72.0	71.5
73.5	73.5	73.5	72.5	71.5	71.0	71.0	71.0	70.5	72.0	71.5
72.5	73.0	72.5	72.0	72.5	72.5	71.5	72.0	69.5	70.5	71.5
72.5	73.0	73.0	73.0	73.0	72.5	71.5	73.0	73.0	72.0	72.0

RUN 11 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.0	73.0	78.0	73.5	73.0	71.5	72.0	70.5	72.0	72.0	72.0
71.5	73.5	74.5	72.0	71.0	71.5	71.5	70.0	71.5	71.5	72.5
73.0	73.5	73.0	71.5	72.5	71.0	72.0	70.5	71.0	71.5	[illegible]
72.0	73.0	73.5	72.5	72.5	71.5	71.0	71.5	70.0	70.5	72.0
73.0	73.0	72.0	72.0	72.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 12 REPLICATE 1

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
73.0	72.5	72.0	72.0	72.5	73.0	72.5	72.5	72.0	72.5	72.0
72.5	72.5	72.0	72.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
72.0	72.0	72.0	72.0	72.5	72.0	72.5	72.5	72.0	73.0	[illegible]
72.0	72.0	72.5	73.0	72.5	72.0	73.0	72.0	72.0	72.0	72.5
72.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RUN 12 REPLICATE 2

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.5	72.5	72.5	73.0	72.5	73.0	73.5	72.5	73.0	73.5	72.0
72.0	72.0	72.5	72.5	72.5	71.5	71.5	73.0	73.0	72.5	[illegible]
72.5	72.5	71.5	72.0	72.0	72.5	71.5	72.0	72.5	73.0	[illegible]
72.0	72.0	72.0	73.0	72.5	72.5	72.5	72.0	72.5	72.0	73.0
72.5	72.5	71.0	71.5	71.5	72.0	72.5	72.0	72.0	72.5	72.0

RUN 12 REPLICATE 3

218.0	*	173.5	*	132.5	*	91.5	*	50.5	*	15.0
72.5	72.5	73.0	72.5	72.5	72.5	72.5	72.0	73.0	73.0	72.5
73.0	72.5	73.0	71.5	71.5	72.5	71.5	71.5	72.5	73.0	72.5
72.5	72.5	71.5	72.0	72.5	72.5	71.5	72.0	72.0	72.5	[illegible]
[illegible]	[illegible]	[illegible]	71.5	72.5	72.5	72.0	72.0	72.0	72.0	72.0
[illegible]	[illegible]	[illegible]	72.5	72.0	72.0	72.5	72.5	72.5	72.5	[illegible]